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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 14 September 1955, the Chair being taken by A. C. Hartley, C.B.E., a vice-president of the Institute.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting.

The Chairman, introducing the author of the paper to be presented, said: The paper tonight is being given by the author, Mr J. M. Dougary.

Mr Dougary took an honours degree in chemistry in the University of London, and joined the Anglo-Iranian Oil Company (now The British Petroleum Co Ltd) in Abadan at the beginning of 1935. After some general experience there, he, with a group of chemists, was designated to commission and develop the process and pilot plants for the production of 100 O.N. aviation gasoline. He was engaged on that sort of work for most of the rest of his period in Abadan. Then, in 1946, he joined the Kuwait Oil Company as superintendent of the Storage and Export Division, in preparation for the start of the exports from Kuwait which began in June 1946. The exports, rising from nil, as we shall hear in the paper, are running currently at over one million b.d., and Mr Dougary has been very intimately connected with the whole of the development of the facilities to enable this to be done. He became assistant superintendent of the Pipeline and Export Department in 1951. He is a Fellow of the Royal Institute of Chemistry, an Associate Member of the Institution of Chemical Engineers, and has been a Fellow of the Institute of Petroleum for some years. He was elected to the committee of the Kuwait sub-branch in 1953, was vice-chairman in 1954, and is the chairman of that branch this year.

The following paper was then presented in summary by the author:

MODERN CRUDE OIL LOADING TECHNIQUES AT MINA-AL-AHMADI, KUWAIT *

By J. M. DOUGARY (Fellow) †

SUMMARY

The paper describes the build up of crude oil loading capacity at the Mina-al-Ahmadi loading terminal of Kuwait Oil Co. Ltd., from the time of the initial shipment in June 1946 until March 1955, when exports had reached in excess of 1·0 million b.d. The facilities which have been provided and the methods adopted to enable the high export rates to be met are described and discussed.

INTRODUCTION

IN June 1946, from the time of the first crude oil shipment from Kuwait, sixty-one crude oil shipments were made for a total of just under 800,000 tons. In 1954 just under 2500 vessels were loaded, and exports exceeded 45 million tons. Table I records the average b.d. receipts from the Burgan and, latterly, Magwa fields. It also records the number of ships loaded and the corresponding tons and barrels up to the end of March 1955.

To enable the rapid and very substantial increase in exports to be made, it was necessary to build up a system of pipeline from the producing areas, tankage to receive the oil, and a system of gravity lines to deliver the oil to the loading terminal. In the present paper a short historical section describes the growth of facilities before describing in detail the present status and how these facilities are utilized (see Fig 1).

HISTORICAL

1946. Tankage available: four of 139,000 brl.
One 22-inch gravity line from tank farm to loading terminal.
Two submarine loading berths (two 12-inch lines, two 8-inch submarine loading hoses).

TABLE I

Crude Oil Receipts and Loadings

Year	Receipts from the fields, b.d.	No. of ships loaded	Tonnage	U.S. brl at 60° F
1946 *	28,786 *	61 *	768,861 *	5,689,571 *
1947	44,460	168	2,113,646	15,694,414
1948	127,177	436	6,224,815	46,198,776
1949	246,385	802	12,010,102	88,643,985
1950	344,445	973	15,797,037	116,696,003
1951	561,396	1693	26,623,054	196,334,760
1952	747,084	2247	35,771,961	264,028,271
1953	861,897	2435	41,034,474	302,997,936
1954	951,560	2497	45,483,146	336,315,861
1955 †	1,062,594 †	685 †	12,622,285 †	93,562,762 †

* From 30 June to 31 December.
† For first three months only.

1947. Tankage available: six of 139,000 brl.
1948. Tankage available: six of 139,000 brl.
two of 168,000 ,,
two of 90,000 ,,
A second 22-inch gravity loading line was commissioned in March.
Three additional submarine loading berths were commissioned in October and December (each two 12-inch lines, two 8-inch submarine loading hoses).

* MS received 14 July 1955.

† Kuwait Oil Company Ltd., Kuwait.

FIG 1

1949. Five additional 168,000-brl tanks commissioned. (Two 90,000-brl tanks reverted to bunker fuel duty.)
Oil jetty commissioned 23 November (crude oil berths).
Three additional 24-inch gravity lines commissioned.

1950. Six additional 168,000-brl tanks commissioned.

1952. Four additional 168,000-brl tanks commissioned.
A sixth 30-inch gravity line commissioned.

1953. Two further 168,000-brl tanks commissioned.
A seventh 34-inch gravity line, and an eighth combination 30–34-inch gravity line was commissioned.

1954. Three additional 168,000-brl tanks commissioned.
Three new submarine loading berths commissioned (one single 24-inch line and 12–10-inch loading hoses to each).

1955. Four additional 210,000-brl tanks commissioned.

PRESENT STATUS OF CRUDE OIL LOADING INSTALLATIONS

Reference should be made to the schematic drawing "Kuwait Oil Co. Ltd., Crude Oil Loading Installations" (Fig 2).

Crude oil from Burgan field is pumped through one combination 20–22-inch and two 20-inch lines, and from the Magwa field through one 16-inch line, the two streams being manifolded to provide adequate mixing at the Ahmadi distribution manifold. At this point the main crude oil stream is routed to serve the various tank groups by means of 20-inch lines and 20-inch filling laterals into groups of three or four tanks. The filling lines for individual tanks are 12-inches dia.

AHMADI TANK FARM

Ahmadi tank farm at the present time consists of thirty-two tanks on crude oil service of the following capacities: six of 139,000 brl each; twenty-two of 168,000 brl each; four of 210,000 brl each.

As a generalization, tanks are grouped in banks of four, each tank group serving one of the gravity lines which are used for loading. Each tank group is used thus:

One filling from the field; a second standing empty to receive oil when the filling tank is switched; a third loading; and a fourth tank standing full or partially full to complete the loading for the increasing number of large-capacity tankers loading. Total installed capacity amounts to just over 5 million brl, with an effective capacity of 4·6 million brl.

Ahmadi tank farm, located at between 370 and 400 ft above sea level and approximately 6 miles east of the shore terminal at Mina-al-Ahmadi, is connected to the shore terminal by eight gravity lines, by which all loading is carried out.

GRAVITY LINES

The gravity line system is split into two parallel routes approximately one mile apart, but cross-connected, both at the Ahmadi tank farm end and at the shore terminal, to provide flexibility. The first gravity line group system of Nos. 1 and 8 comprises one 22-inch line throughout its length connected to four 139,000-brl tanks. No. 8 gravity line is a combination 30–34-inch line to its junction with the submarine loading manifold.

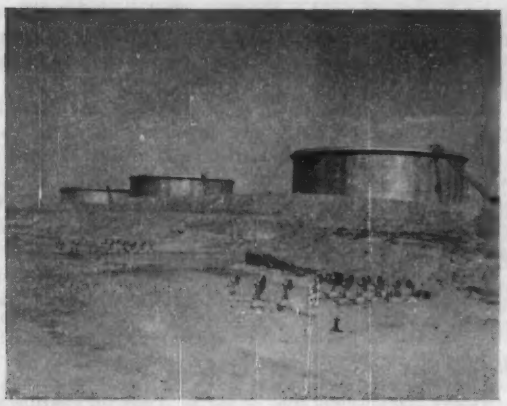
In the second and larger gravity line system, there are:

One 22-inch line, three 24-inch lines, one 30-inch line, and one 34-inch line. Apart from the 34-inch

TANK FARM, GENERAL VIEW, SHOWING LOADING LATERALS AT THE BASE OF THE FIRE WALLS

line, which is connected to the four 210,000-brl tanks by a 34-inch lateral, all the remaining gravity lines are connected to their respective tank groups by twin 22-inch laterals, again to provide maximum flexibility. Apart from the 34-inch lateral serving the large-diameter gravity lines, all other laterals are tied into each of the six gravity lines in the main gravity line manifold which runs from east to west throughout the tank farm.

The six gravity lines described terminate in the jetty switchgate manifold, where the final routing on shore of the crude oil streams takes place. Valve arrangements here are such that a very high degree of flexibility is provided. The jetty switchgate manifold is also connected to the submarine switchgate manifold by one 22-inch and three 24-inch cross-connexions, thus further increasing the flexibility of the loading system. From the jetty switchgate manifold the oil stream splits into eight segregated loading lines, each



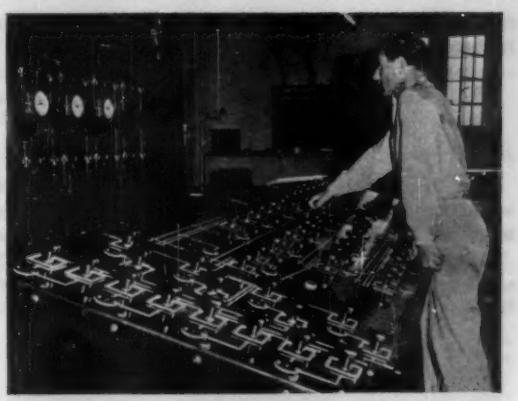
TANK FARM MAIN GRAVITY LOADING MANIFOLD

of 24-inch dia on to the approach pier of the oil and cargo jetty.

OIL AND CARGO JETTY

A very full description of the design and construction of the Mina-al-Ahmadi oil and cargo jetty was presented before the Institute of Civil Engineers in January 1952, by McGowan, Harvey, and Lowdon, in their paper "Oil Loading and Cargo Handling Facilities at Mina-al-Ahmadi, Persian Gulf."

In the present paper, therefore, description is confined to the crude oil loading lines and systems (and in a later part of the paper to bunkering lines and arrangements). On the oil pier proper there are four berths on the seaward side and two on the landward side. Available at each berth are four loading connexions from the 24-inch loading lines. When loading at peak capacity, normally only two of the loading connexions are used, but at anything below peak loading rates, three or four loading connexions are used for vessels capable of taking cargo at rates up to 4000 tons/



TANK FARM OPERATOR USING REMOTE CONTROL OF TANK INLET VALVE

hr. In addition to the six berths on the oil pier proper, the cargo pier has been converted for crude oil loading by taking connexions from the eight 24-inch loading lines by means of three 22-inch lines—one from jetty loading lines 1 and 2, one from jetty lines 3–6, and one from jetty loading lines 7 and 8. As on the oil pier, each of the two crude loading berths on the cargo pier have four loading connexions. Apart from two of the loading connexions at No. 2 berth which are fitted with two 10-inch smooth-bore hoses, all other berths are fitted with 8-inch smooth bore loading hoses, although it is the ultimate intention to have all berths provided with 10-inch or even possibly 12-inch loading hoses. Each of the jetty loading lines terminates in a terminal header valve, which enables oil from one loading line to be passed back to another of the loading lines, thus further increasing the flexibility of the loading system. The terminal header valves can only be used one at a time in the manner described.

SUBMARINE LOADING BERTHS

In addition to the crude loading berths on the oil pier, three submarine berths are also operated in order to deal with shipping congestion resulting from "bunching," especially after loading has been suspended on account of unfavourable weather. Each submarine berth consists of a single 24-inch dia line terminating in 12–10-inch heavy-duty submarine loading hose (each berth is supplied with a separate 12-inch bunkering line; this facility is described later).

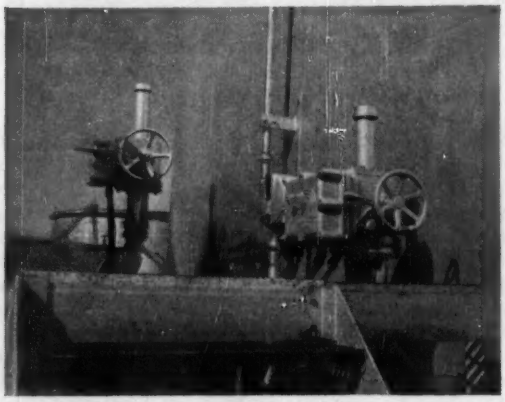
From the description and a study of the schematic drawing of the crude oil loading installation, the facilities provided give a large degree of flexibility, thus enabling high export rates to be achieved. It should be noted that the high degree of flexibility in the crude oil loading systems is only possible because at the present time one grade of crude oil is being produced and exported. Even so, the physical distances to be covered and the number of valves required to be operated would make it necessary to employ a very substantial manpower force were it

not for the provision of operational aids installed to reduce manpower requirements to a minimum.

AUTOMATIC AND REMOTE CONTROL EQUIPMENT

Remote-operated Electrical Control Valves

The most important of the operational aids provided are the remote-operated electrically controlled inlet and outlet valves on each of the tanks in the Ahmadi tank farm. In order to operate satisfactorily eight gravity lines from the Ahmadi tank farm to the terminal, a minimum of thirty-two tanks are required



TANK FARM CLOSE UP OF ELECTRICALLY OPERATED 12-INCH INLET AND 20-INCH OUTLET VALVES
Note the liquid level gauge between the two valves.

for use in the manner described, *i.e.* one filling from the field, one empty and available for switching into, one loading, and one available to switch from to complete loading. At any one time, crude oil is being received from the field areas into each one of the eight tank groups. Equally, it is not uncommon for up to ten tanks to be used simultaneously for export operations. (When possible two tanks are employed in parallel when using the large capacity gravity lines.)

Groups of four tanks, therefore, are allocated to each of the eight gravity lines with the appropriate valves in the main gravity line manifold, and the tank outlet lateral valves set. These valves are all manually operated. In the Ahmadi tank farm, this leaves only the 12-inch electrically operated tank inlet valve, and the 20-inch electrically operated tank outlet valve, to be operated. (It should be noted that although motor operated valves have been provided on all tanks, some work remains to be done before valves on the most recently completed tanks can be power operated.)

In normal circumstances, therefore, it is unnecessary to use the manually operated valves which have been provided, each filling and loading system being self-sufficient. However, when abnormal conditions prevail, as a result of excessively high or low oil stocks, a large degree of flexibility is available to cater for the abnormal conditions.

The electrically operated inlet and outlet valves can be operated from the tank side by suitable press buttons either "open," "close," or "stop." Interlocking arrangements are provided to ensure that both inlet and outlet valves cannot be opened simultaneously. Control of tank farm operations is carried out from a farm tank control building, and it is from there that the electrically operated inlet and outlet tank valves are normally opened or shut as required. A control panel designed and constructed by the Charles Langais Company of California is located in the control building, which is something over a mile from the most remote tank in the tank farm.

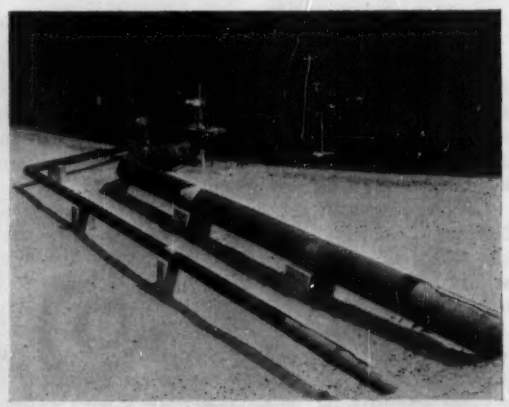
Incorporated in the control panel is a schematic arrangement of tanks, lines, and valves corresponding to the actual arrangement in the tank farm, with a control desk from which the electrically operated valves are operated. On the control panel each valve has red and green indicator lights; when the valve is shut the green indicator is illuminated, and when the valve is open the red indicator is illuminated. When valves are being opened or shut, both lights show until the valve is either completely open or completely shut.

A similar control panel is provided at the switchgate manifold of the shore terminal. This is the central point of all crude loading operations, and from where oil from the gravity lines is routed on to the eight jetty loading lines. Here, some forty 20-inch valves are electrically operated from the control panel in a similar way to those in the tank farm.

The importance of this operational aid in speeding and facilitating filling and loading operations will be readily appreciated.

Remote-reading Liquid Level Gauges

It has been stated that as far as crude oil loading is concerned, up to eight tanks in the tank farm may be filling simultaneously from the field areas, and at the same time a further ten tanks may be in movement for export operations, *i.e.* a total of eighteen tanks in



TANK FARM 12-INCH FILLING LINE AND ELECTRICALLY OPERATED INLET VALVE, 34-INCH OUTLET LINE AND 24-INCH ELECTRICALLY OPERATED OUTLET VALVE

TABLE II

Gravity Line Capacities

Gravity line	Size of line		Size of loading hoses, inches	Number of tanks used	Normal hourly loading rates, tons/hr			Remarks
	Gravity line, inches	Jetty loading line, inches			2 hoses	3 hoses	4 hoses	
No. 1	22	24	8	1	1450	—	—	The use of two tanks on 22-inch or 24-inch gravity lines gives an increased loading rate of approx 50 tons/hr. One or two additional hoses give an increased rate of approx 50 tons/hr only.
,, 2	22	24	8	1	1450	—	—	
,, 3	24	24	8	1	1750	—	—	
,, 4	24	24	8	1	1750	—	—	
,, 5	24	24	8	1	1750	—	—	
,, 6	30	24	8	2	2450	2800	3000	The use of a single tank on 30-inch and 34-inch gravity lines reduces the loading rate on two hoses by approx 100 tons/hr. A single tank is not used on more than two hoses. Loading rates are applicable to tanks loading at a dip in excess of 20 ft.
,, 7	34	24	8	2	2700	2950	3200	
,, 8	30–34	24	8	2	2300	2500	2700	

Notes: (*a*) Rates given above are for the oil jetty. On the cargo jetty (20–22 inch loading line extensions), hourly rates on 22-inch and 24-inch gravity lines are reduced by approx 150 tons/hr, and for 30-inch and 34-inch gravity lines by approx 300 tons/hr.

(*b*) Provided the vessel loaded has a 10-inch connexion, the use of 10-inch hoses enables increased loading rates of 100 tons per hose. This applies to all size gravity lines using two tanks simultaneously.

movement simultaneously. A large gauging force would be necessary to keep oil movements up to date, and to determine when filling or loading tanks were required to be switched. Accordingly, liquid level gauges have been provided or are being provided for all crude tankage used in export operations. The gauges are of the float type, attached to a wire passing over pulley sheaves at the top of the tank shell, down to the measuring drum of the gauge at ground level. The oil level at each tank can, therefore, be read (at the tank base) without using conventional gauging methods, but even more important is the transmitter arrangement, which enables the oil level to be read on a receiver in the tank farm control room, thus enabling an up to the minute record of all tanks in movement to be immediately available in the control building, since each tank is provided with an individual receiver. It should be noted that the remote reading liquid level gauges are used at the present time only for operational purposes. All official measurements for royalty and export purposes are still carried out by conventional means, *i.e.* by dipping with certified dip tapes, and associated temperature measurements. With more accurate and reliable liquid level gauges now being manufactured and tested, it is not unreasonable to hope that it will not be too long before official measurements will be acceptable using liquid level gauge readings.

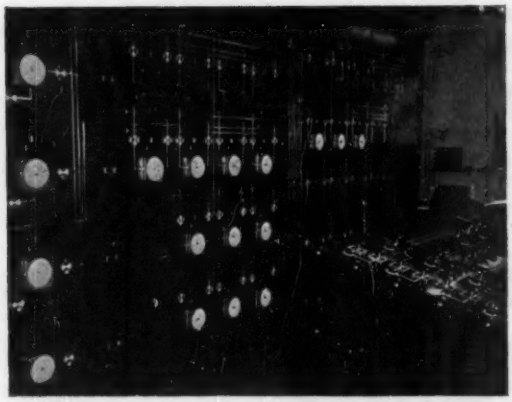
Automatic Resistance Thermometers

A further operational aid which it is proposed to experiment with is to be installed in one of the Ahmadi tanks in the immediate future. This is the Weston averaging resistance thermometer, which would obviate the need for time-consuming, tedious, conventional methods using the standard temperature sampler. The Weston thermometer is based on the alteration in resistance of metals with temperature, and temperatures can be read off directly from a gauge at the tank base, and would obviate the necessity for top-, middle-, and bottom-temperature readings being made from the roof of the tanks.

TABLE III

Gravity Line–Jetty Loading Line Combinations for Loading Rates Exceeding 2000 Tons/Hr

Rate, tons/hr	Size of gravity lines used, inches	No. of 8-inch hoses	No. of jetty loading lines	Oil–cargo pier
2000	2 × 22	2	1	Oil
2000	2 × 22	2	2	Cargo
2200	2 × 22	2	2	Oil
2200	1 × 22 and 1 × 24	2	2	Cargo
2300	1 × 22 and 1 × 24	2	1	Oil
2400	2 × 24	2	2	Cargo
2500	2 × 24	2	1	Oil
2700	2 × 24	2	2	Oil
2700	1 × 22 and 1 × 24	3	2	Cargo
2850	2 × 24	3	2	Cargo
3000	1 × 22 and 1 × 24	3	2	Oil
3200	2 × 24	3	2	Oil
3200	2 × 24	4	2	Cargo
3500	1 × 30 and 1 × 24	4	2	Cargo
3500	2 × 24	4	2	Oil
3800	1 × 34 and 1 × 22	4	2	Cargo
3900	1 × 34 and 1 × 24	4	2	Cargo
4000	2 × 22 and 1 × 24	4	2	Oil
4000	1 × 22 and 1 × 30	4	2	Oil
4200	1 × 22 and 2 × 24	4	2	Oil
4200	1 × 30 and 1 × 24	4	2	Oil
4200	3 × 24	4	3	Cargo
4200	1 × 34 and 1 × 22	4	2	Oil
4300	1 × 34 and 1 × 24	4	2	Oil
4000	1 × 34 and 1 × 30	4	2	Cargo
4500	1 × 34 and 1 × 30	4	2	Oil



TANK FARM—GENERAL VIEW OF CONTROL ROOM SHOWING REMOTE-READING LIQUID-LEVEL GAUGES AND CONTROL PANEL

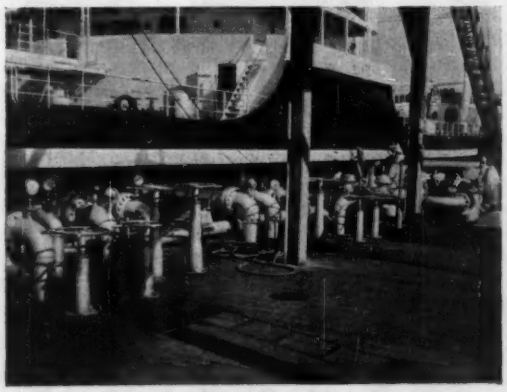
BUNKERING FACILITIES

Although bunkering operations are, strictly speaking, a completely separate part of the terminal facilities, they are so intimately connected with crude loading operations that it is convenient to comment on them at this juncture. Both furnace oil and marine diesel oil bunker fuels are available at all jetty berths. At one of the submarine berths only marine diesel is provided, at the other two furnace oil only is available. For furnace bunker deliveries, the jetty is fed from a 16-inch line with twin 8-inch off-takes (to suit the ship's bunkering connexions) at each of the oil pier berths. A 6-inch connexion from the 16-inch line feeds the two cargo pier berths. For each of the submarine berths, one 12-inch line "tees-off" a combination 20–16-inch shore feeder line. For marine diesel deliveries, a 12-inch line is used on the oil and cargo pier with twin 8-inch take-off lines at each of the oil pier berths. On the cargo pier marine diesel deliveries are made from a 6-inch connexion from the main 12-inch delivery line with twin 6-inch connexions to each of the two cargo pier berths. The largest size hoses which can be successfully used are available, but the actual size connected is dependent on the ship's connexions and bunker lines. Deliveries of both grades of bunker fuels are by pump from shore measuring tanks; in the case of furnace oil varying in size from 168,000 to 10,000 brl capacity, and in the case of marine diesel, from 90,000 to 10,000 brl capacity.

The capacity of the bunker loading pumps varies according to winter or summer conditions, approx 350 tons/hr in summer, and about 300 tons/hr in winter. In the original bunker installations it was only possible to bunker one ship at a time with either grade of fuel, and in so far as marine diesel oil is concerned this is still perfectly adequate, but in the past few years, especially with the advent of the super tanker requiring up to 2500 tons of furnace oil, or in isolated cases even more, serious delays were incurred and valuable jetty time lost by vessels completing their crude oil cargo prior to the completion of bunkers.

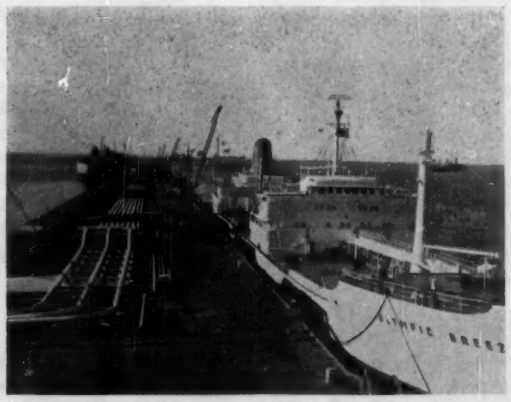
To obviate or eliminate bunkering delays, it was necessary then to speed up bunkering deliveries either by duplicating the existing bunkering system or by the use of meters at individual berths from the single 16-inch delivery line. A trial installation of positive displacement meters was tested extensively over an eighteen month period, with remarkably close agreement between quantities calculated from meter readings and quantities calculated from tank measurements using conventional gauging methods. On the basis of these results a decision was made to instal positive displacement meters for furnace bunker deliveries at all berths. Prior to their installation, these meters are proven and certified at a test bed especially provided for the purpose.

Over the past year, oil and cargo pier berths have been fitted with meters, and the confidence placed in their accuracy has been amply vindicated, for example, in January 1955, 400,000 brl of furnace bunkers were delivered, and showed a difference of 246 brl from



OIL PIER CRUDE AND BUNKER VALVE ARRANGEMENTS

At extreme right, meter bank for measuring furnace bunker deliveries.



OIL PIER—GENERAL VIEW AT PEAK LOADING

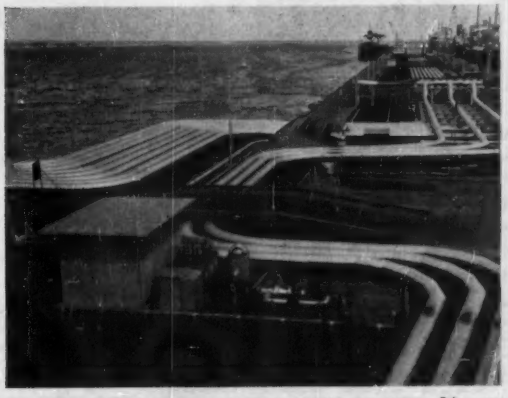
At the time this photograph was taken the cargo lifted by vessels alongside was over 191,000 tons.

tank gauge measurements, a difference of 0·06 per cent. In February 1955, 500,000 brl were delivered through the meters for a difference of 273 brl or 0·05 per cent.

These are the facilities which have been provided for crude oil loading and bunkering operations. A discussion on how these are used follows.

GRAVITY LINE CAPACITIES

Since 1951 approx 10,000 tankers have been loaded at the oil and cargo pier at Mina-al-Ahmadi, and it has been possible to establish accurately the loading rates which can be achieved with each of the gravity lines and loading systems installed. These are detailed in Table II, which shows that loading rates vary on a single gravity line system from 1450 tons/hr for the 22-inch gravity line to 3200 tons/hr on the 34-inch gravity line. When all berths on the oil and cargo pier are operating simultaneously, it is not possible to exceed for any one ship the maximum loading capacity



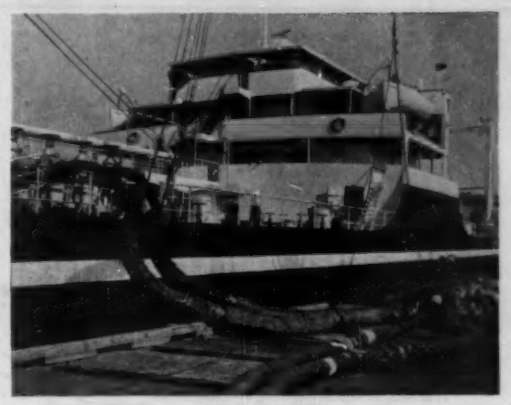
OIL AND CARGO PIER—GENERAL VIEW SHOWING 24-INCH LOADING LINES TO OIL PIER AND 22-INCH LINES TO CARGO PIER

of the gravity line system to which it is connected. However, by the nature of the loading operations it is unusual for loading to be in progress simultaneously at all berths, since at one or more other operations than direct loading are normally taking place, such operations would include tying up, unmooring, deballasting (this being the most common). When these operations other than direct loading are in progress, whenever it is expedient to do so, an additional gravity line or gravity lines is added to the loading system for vessels capable of loading at rates in excess of a single gravity line capacity.

By these means, it is impossible to obtain a gravity line utilization of up to 90 per cent. It will be appreciated that an additional gravity line system is used only when a reasonable utilization of the additional loading system can be made, *i.e.* 3 hr or more.

LOADING CAPACITY

Over the past few years it has been possible to establish the loading rates which can be achieved with various



OIL PIER SHOWING CRUDE LOADING AND BUNKER HOSE ARRANGEMENTS

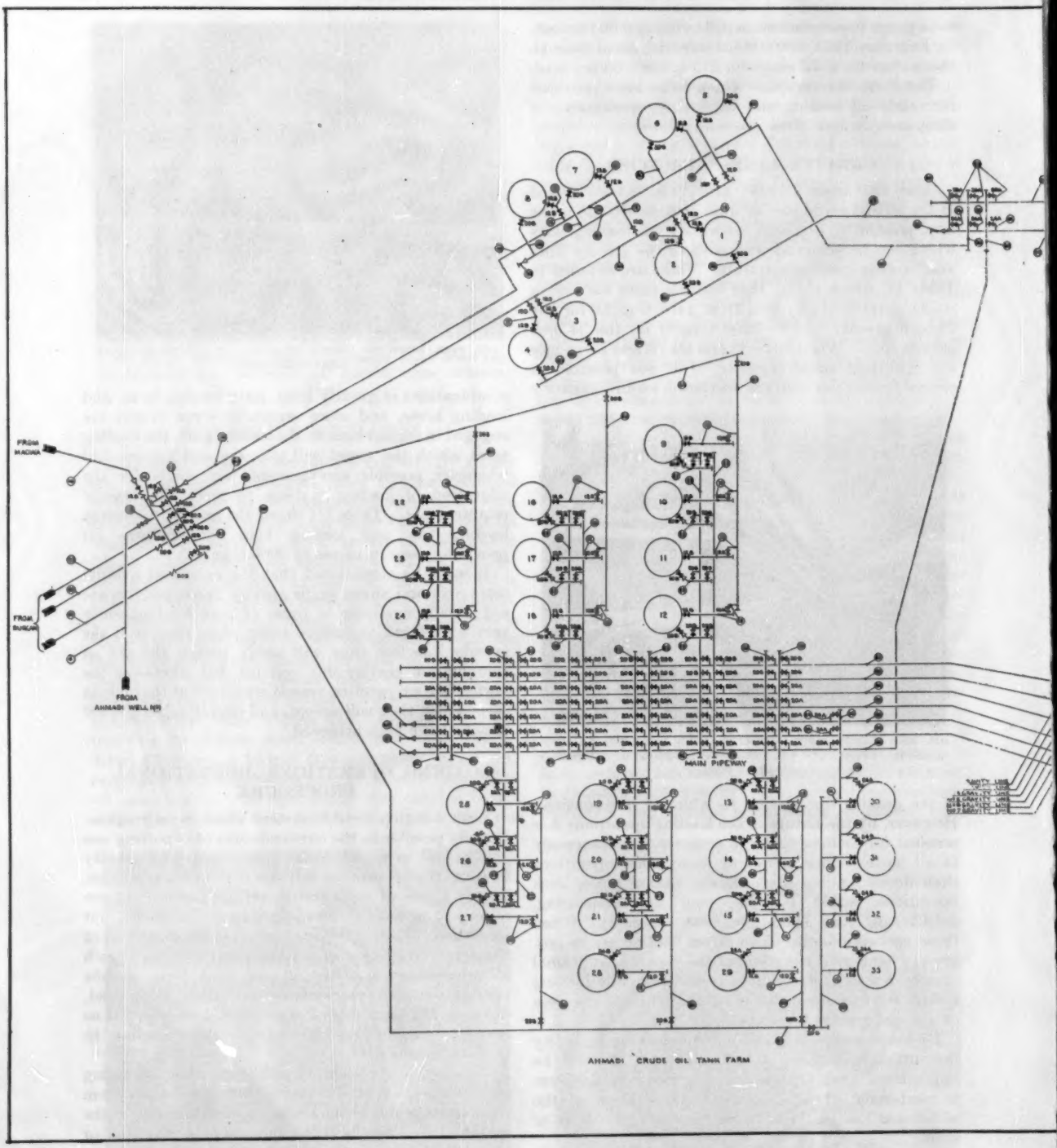
combinations of gravity lines, jetty loading lines, and loading hoses, and more especially when vessels are engaged in regular runs to the loading port, the loading rates which the vessel will take are well known, and whenever possible arrangements are made for the allocation of loading systems to meet the vessels' requirements. Table III shows the gravity line, jetty loading line, and loading hose combinations for providing rates in excess of 2000 tons/hr.

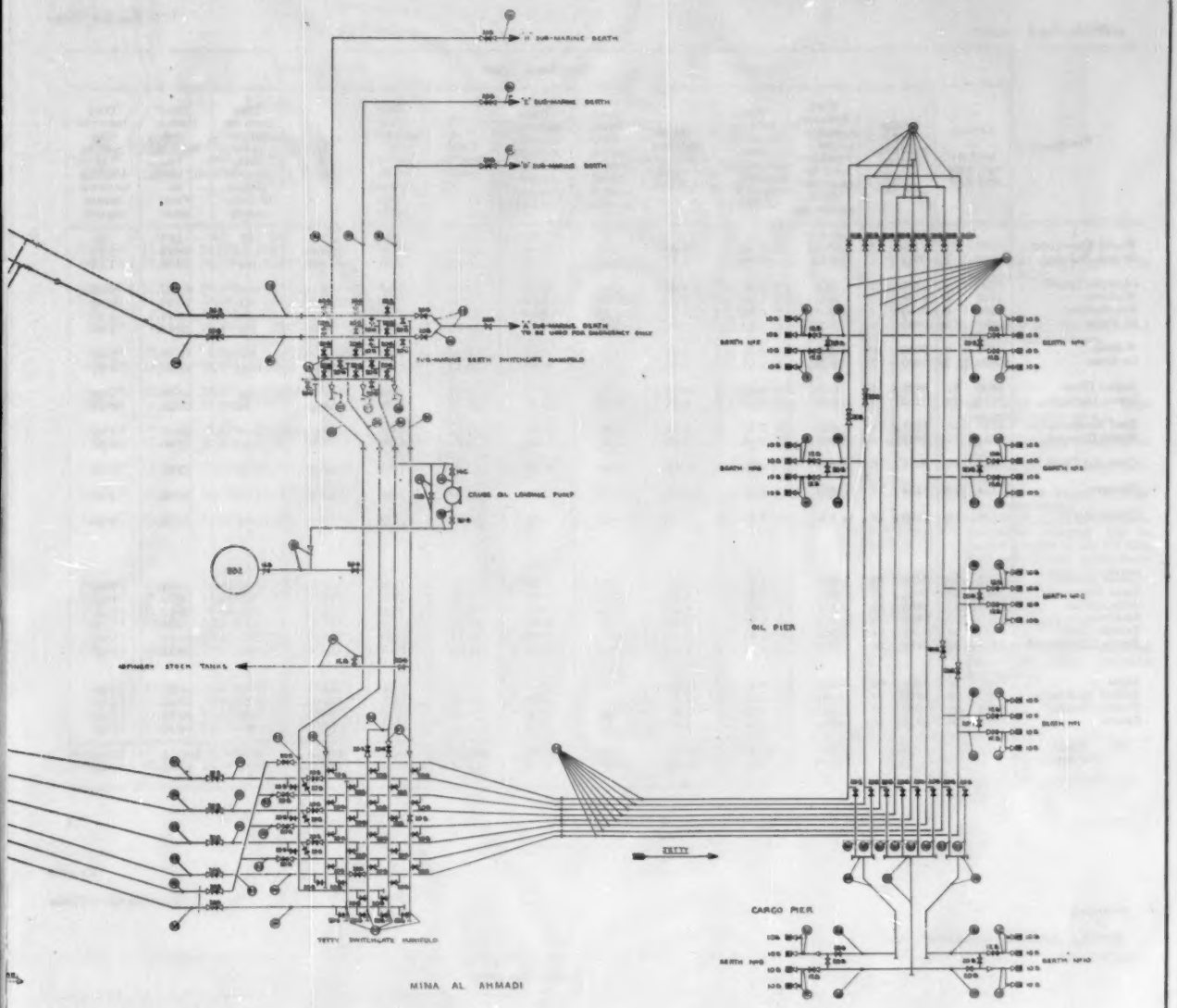
It must be emphasized that the enhanced loading rates over and above single gravity line capacities are not usually available at times of peak loading, since very high berth utilization takes place then, and the gravity line free time will rarely permit the use of combination gravity line systems, but whenever the port condition permits, vessels are loaded at the highest rates which they will accept, and overall rates of 4000 tons/hr have been achieved.

LOADING OPERATIONS—OPERATIONAL PROCEDURE

With a highly flexible system which is only operationally possible in the circumstances of exporting one grade of oil only, and using almost exclusively gravity loading, the operational side is a relatively simple one, but by virtue of these factors certain precautions are necessary to enable the operations to be carried out smoothly. The switchgate control at the shore end of the terminal is used as a focal point through which all information from the oil pier, tank farm, marine operations, and documentation office is passed, enabling the large degree of co-ordination which is so necessary in handling eight to nine ships per day, to be done so smoothly.

To avoid any possibility of line draining, all lining up of loading systems is carried out successively from the highest points of the loading system through to the loading valves at the ship's side, namely, the tank or tanks in the Ahmadi tank farm (at 400 ft above sea level) are lined up first through the tank laterals to the main gravity line loading manifold. Then, lining up is carried out at the switchgate manifold before


FROM
MADURA
FROM
BURGAN
FROM
AHMADI WELL NO
MAIN PIPEWAY
AHMADI CRUDE OIL TANK FARM



THIS DRAWING SUPERCEDES DRG NO PLS/1/84 - REISSUED

LEGEND			
NON-GEAR OPERATED GATE VALVE		PUMP	
GEAR OPERATED GATE VALVE		LINE DIAMETER (NOMINAL)	
ELECTRIC MOTOR OPERATED GATE VALVE	A	SERIES 150	
GEAR OPERATED PLUG VALVE	B	SERIES 300	
CHECK VALVE	C	400 LBS WOG. SERIES 300 FLANGES	
REDUCER	D	600 LBS WOG. SERIES 300 FLANGES	
EXAMPLE – 8" / 10"			
GEAR OPERATED GATE VALVE 10" SERIES 300 IN 24" LINE WITH 24"-10" REDUCER			

KUWAIT OIL Co L^TD	
CRUDE OIL LOADING INSTALLATIONS	
SCALE: NOT TO SCALE	DATE:- 4/4/85
DRAWN BY:- Jal Rogers	CHECKED BY:-
APPROVED BY:-	
DRG NO KOL 1510	DRG NO PLS/1/85

TABLE

Tanker Time

Berth No. 6

Vessel	Operational Times: Arrival at anchorage, time and date		Notice of readiness to load, time and date		Time between notice of readiness and departure from anchorage	Time between departure from anchorage and arrival at berth	Time to deballast from arrival at berth	Time from completion deballasting to tank inspection	Time between tanks inspection and commencement of loading	Total time to load	Time from completion of loading to departure from berth	Time in berth	Time from departure from berth to completion of documents	Total time in port from N/R to ex berth or clearance	Time between completion of loading to documents signed
1	2		3		4	5	6	7	8	9	10	11	12	13	14
World Enterprise	0700	31	0700	31	Nil	1·36	4·49	0·10	0·05	19·50	1·00	25·54	1·15	28·45	2·15
British Bulldog	0942	1	0942	1	0·33	1·09	3·56	0·10	0·35	10·45	2·00	17·26	Nil	19·08	1·25
Olympic Laurel	0820	2	0820	2	Nil	0·40	4·40	0·05	0·10	11·35	1·48	18·18	0·27	19·25	2·15
Wallowa	1130	3	1130	3	Nil	1·00	3·35	0·05	0·10	9·50	1·40	15·20	Nil	16·20	1·40
Beaufighter	0454	4	0454	4	Nil	0·46	5·30	0·10	0·10	11·35	1·37	19·02	Nil	19·48	1·10
El Mirlo	0445	5	0445	5	Nil	1·07	7·38	0·05	0·15	12·35	2·03	22·36	Nil	23·42	1·25
Wilstar	0600	6	0600	6	Nil	0·55	3·05	0·05	0·05	6·45	1·23	11·23	Nil	12·18	1·05
La Cruz	0530	7	0530	7	0·35	0·51	3·19	0·10	0·30	13·45	1·18	19·02	0·32	21·00	1·50
Rogue River	0600	11	0600	11	0·30	0·45	10·05	0·10	0·10	9·45	2·05	22·15	Nil	23·30	1·30
Sovac Daylight	0410	12	0410	12	2·05	0·42	6·33	0·10	0·30	16·45	1·50	25·48	0·45	29·20	2·35
Esso Southampton	1210	13	1225	13	Nil	0·31	4·59	0·10	0·10	15·40	1·09	22·08	1·16	25·55	2·25
World Concord	0645	15	0645	15	Nil	0·45	5·55	0·10	0·10	9·45	1·12	17·12	0·43	18·40	1·55
Chisholm Trail	0615	16	0615	16	Nil	0·30	7·15	0·10	1·05	15·10	1·10	24·50	0·30	25·50	1·40
Vanessa	1134	17	1134	17	Nil	0·31	5·35	0·10	0·10	12·30	1·25	19·50	1·05	21·26	2·30
Clutha River	1030	18	1030	18	Nil	0·32	5·18	0·10	0·10	10·45	3·02	19·25	0·18	20·15	2·50
Caltex Glasgow	0833	19	0833	19	Nil	1·07	3·50	0·05	0·20	9·55	1·00	15·10	0·35	16·52	1·35
Tank Emperor	1052	20	1052	20	Nil	0·40	6·28	0·10	0·20	8·15	2·07	17·20	Nil	18·00	1·55
Johannisthus	0900	21	0900	21	Nil	0·23	6·47	0·05	0·15	9·50	2·14	19·11	Nil	19·44	1·45
Storheim	0500	22	0500	22	Nil	1·20	5·25	0·05	0·20	10·20	1·12	17·22	0·17	18·59	1·29
British Glory	0735	24	0735	24	Nil	0·43	8·52	0·10	0·10	10·15	1·30	20·57	Nil	21·40	1·0s
Baron Kilmarnock	1237	25	1237	25	Nil	0·43	4·40	0·10	0·10	10·50	2·15	18·05	Nil	18·48	1·20
Algol	0800	26	0800	26	Nil	0·43	3·22	0·05	0·25	10·05	1·15	15·12	0·35	16·30	1·50
Rudolf Andersson	1010	28	1010	28	Nil	1·23	4·27	0·10	0·05	10·20	1·00	16·02	0·20	17·45	1·20
Purfina France	1230	29	1230	29	Nil	0·40	7·55	0·05	0·05	10·00	0·40	18·45	0·50	20·15	1·30
Symra	0815	30	0815	30	Nil	0·35	4·25	0·05	0·10	8·15	1·10	14·05	Nil	14·40	1·05
25 Total					3·43	20·47	138·23	3·20	6·45	285·05	39·05	472·38	9·28	506·36	43·24
Average					0·09	0·50	5·32	0·08	0·16	11·24	1·34	18·54	0·23	20·16	1·44

TABLE

Tanker Time

Summary of Berths [excluding submarine berths]

Berth	Vessels	Operational Times: Arrival at anchorage, time and date	Notice of readiness to load, time and date	Time between notice of readiness and departure from anchorage	Time between departure from anchorage and arrival at berth	Time to deballast from arrival at berth	Time from completion deballasting to tanks inspection	Time between tanks inspection and commencement of loading	Total time to load	Time from completion of loading to departure from berth	Time in berth	Time from departure from berth to completion of documents	Total time in port from N/R to ex berth or clearance	Time between completion of loading to documents signed
1		2	3	4	5	6	7	8	9	10	11	12	13	14
1	24	—	—	11·44	17·45	107·05	2·45	7·20	248·45	31·34	397·29	9·31	436·29	34·00
2	32	—	—	22·11	22·40	173·18	4·15	8·20	306·35	44·11	536·49	14·54	596·34	54·55
3	30	—	—	11·55	21·32	166·57	3·55	12·45	291·45	42·09	517·31	14·35	565·33	51·25
4	26	—	—	5·44	20·41	141·22	2·50	7·10	253·20	32·00	436·42	22·06	485·13	52·05
5	23	—	—	5·42	18·15	114·15	3·05	7·50	229·15	38·30	392·55	8·42	425·34	38·10
6	25	—	—	3·43	20·47	138·23	3·20	6·45	285·05	39·05	472·38	9·28	506·36	43·24
9	15	—	—	3·07	10·27	87·17	2·05	7·25	160·45	23·55	281·27	7·03	302·04	27·20
10	17	—	—	22·21	12·27	98·11	2·15	8·50	200·40	25·24	335·40	15·26	385·54	37·10
Total	192	—	—	86·27	144·34	1,027·08	24·30	66·35	1,976·10	276·48	3,371·11	101·45	3,703·57	358·29
Average	—	—	—	0·27	0·45	5·21	0·08	0·21	10·18	1·27	17·33	0·32	19·17	1·46

IV

Analysis Record

Month : September, 1963

Loading details									Delays						Remarks
Net barrels loaded	Average loading rate, brl/hr	Net tons loaded	Average loading rate, tons/hr	Loading rate requested, tons/hr	Loading rate available, tons/hr	Number of gravity lines used	Number of loading lines used	Number of hoses connected	Hours delay due to weather	Hours delay berthing operations	Hours delay ship's purposes	Hours delay awaiting loading system	Hours delay awaiting bunkers	Hours delay miscellaneous reasons	
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
230,880	11,641	31,216	1,574	2,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
197,783	18,398	26,826	2,495	4,000	3,000	1 and 2 and 3	2	4	Nil	0·33	Nil	0·35	Nil	Nil	37. Inadequate notice given of changed E.T.L.
206,658	17,838	28,016	2,419	4,000	3,200	2 and 3	2	4	Nil	Nil	Nil	Nil	Nil	Nil	
115,465	11,742	15,592	1,586	2,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
114,715	9,900	15,511	1,339	2,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
85,438	6,975	11,544	942	1,000	1,500	2	1	2	Nil	Nil	0·15	Nil	Nil	0·20	26. Ship lining up. 29. Suspended loading—leaking hoses.
70,308	10,406	9,500	1,652	1,200	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
196,060	14,259	26,651	1,938	3,000	2,500	2 and 3 and 5	2	2	Nil	0·35	0·30	Nil	Nil	Nil	26. Ship lining up.
112,138	11,501	15,170	1,566	1,500	1,500	2	1	2	Nil	0·30	Nil	Nil	Nil	Nil	
186,348	11,132	25,208	1,506	4,000	1,500	2	1	2	Nil	2·05	Nil	0·30	Nil	Nil	14. Pressure of work—three ships completed within 45 min.
145,279	8,278	19,638	1,354	1,200	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
226,649	23,650	30,684	3,202	3,000	3,700	2 and 5 and 1	2	3	Nil	Nil	Nil	Nil	Nil	0·10	29. Suspended loading—overflow on board.
112,140	7,916	15,152	1,070	1,000	1,500	2	1	2	Nil	Nil	Nil	1·05	Nil	1·00	29. Suspended loading—ship's purposes.
128,108	10,249	17,309	1,385	3,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	14. Documents on board 40 min. before completion.
129,551	12,051	17,516	1,629	1,500	1,500	2	1	2	Nil	Nil	Nil	Nil	0·30	Nil	14. Completed bunkers to clearance. Documents delayed due to master's desire to see his ship anchored off jetty before leaving bridge to sign documents
106,802	10,771	14,447	1,457	1,600	1,500	2	1	2	Nil	Nil	0·20	Nil	Nil	Nil	26. Ship lining up.
172,485	20,907	23,396	2,836	3,000	3,000	7	1	3	Nil	Nil	0·20	Nil	Nil	Nil	26. Ship lining up.
112,734	11,471	15,232	1,550	1,500	1,500	2	1	2	Nil	Nil	0·15	Nil	Nil	Nil	26. Ship lining up.
129,676	12,550	17,618	1,705	2,000	1,750	3	1	2	Nil	Nil	0·20	Nil	Nil	Nil	26. Ship closing tank lids.
77,353	7,547	10,451	1,020	1,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
120,239	11,731	16,266	1,587	1,500	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	0·35	29. Suspended loading—checking cargo. 10. Other shipping movements.
136,748	13,562	18,479	1,833	3,000	2,000	2 and 3	1	2	Nil	Nil	Nil	0·25	Nil	Nil	
127,482	11,951	17,233	1,616	2,000	1,750	5 then 2	2	2	Nil	Nil	Nil	Nil	Nil	Nil	
114,607	11,461	15,476	1,548	1,800	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
94,582	11,464	12,765	1,547	2,000	1,500	2	1	2	Nil	Nil	Nil	Nil	Nil	Nil	
3,450,226		466,896							Nil	3·43	2·00	2·35	0·30	2·05	
138,009	12,192	18,676	1,660						Nil	0·09	0·05	0·06	0·01	0·05	

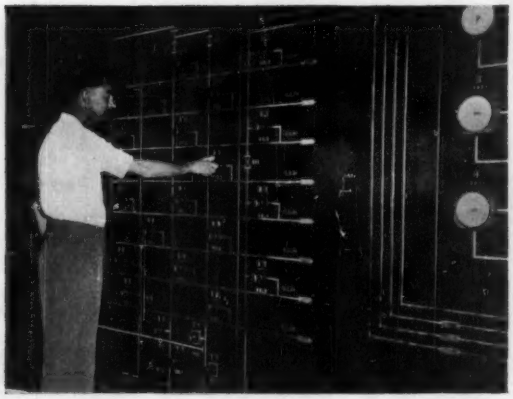
V

Analysis Record

Month : September, 1963

Loading details									Delays						Remarks
Net barrels loaded	Average loading rate, brl/hr	Net tons loaded	Average loading rate, tons/hr	Loading rate requested, tons/hr	Loading rate available, tons/hr	Number of gravity lines used	Number of loading lines used	Number of hoses connected	Hours delay due to weather	Hours delay berthing operations	Hours delay ship's purposes	Hours delay awaiting loading system	Hours delay awaiting bunkers	Hours delay miscellaneous reasons	
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
2,722,320	11,115	369,108	1,507	—	—	—	—	—	Nil	11·44	3·45	2·00	3·05	3·50	Weather delays :
4,077,843	13,396	553,272	1,817	—	—	—	—	—	6·00	16·11	2·55	2·40	Nil	2·10	0830/10–2100/10 = 13·30 hr
3,842,216	13,557	521,640	1,841	—	—	—	—	—	Nil	11·55	4·05	6·10	Nil	8·40	
3,288,181	12,980	445,770	1,760	—	—	—	—	—	Nil	5·44	2·10	2·20	Nil	0·40	13·30 hr
3,068,957	13,387	416,515	1,817	—	—	—	—	—	Nil	5·42	2·50	2·40	4·35	Nil	
3,450,226	12,192	466,896	1,660	—	—	—	—	—	Nil	3·43	2·00	2·35	0·30	2·05	
1,667,033	10,669	225,808	1,445	—	—	—	—	—	Nil	3·07	1·15	1·50	Nil	7·05	
2,432,977	12,570	328,884	1,706	—	—	—	—	—	7·35	14·46	1·05	5·00	1·50	9·45	
24,540,753	—	3,327,893	—	—	—	—	—	—	13·35	72·52	20·05	25·15	10·00	35·00	
127,816	12,602	17,333	1,709	—	—	—	—	—	0·04	0·23	0·06	0·08	0·03	0·11	

N.B.—"HOURS DELAY DUE TO WEATHER" is the amount of time that a vessel is in port and awaiting berth, during a period of bad weather.



SWITCHGATE CONTROL MANIFOLD OPERATOR OPENING LOADING VALVE

making such alterations as are necessary on the loading piers, leaving only the loading valves at the ship's side to be opened when loading is required to be started.

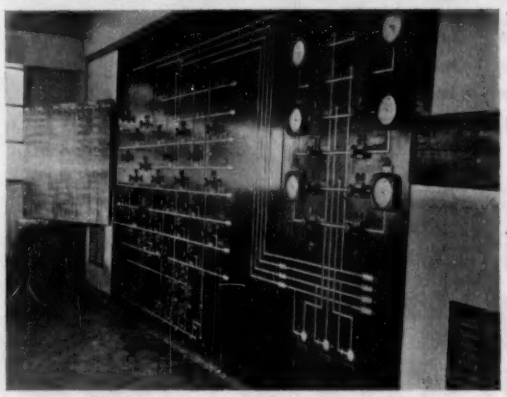
Experience has shown that it is expedient to cut back loading rates nearing the termination of loading to avoid any possibility of line draining from the gravity line system (this is convenient as far as the loading vessel is concerned while topping up tanks). Minimum tank dips have been established, as well as minimum loading pressures on which loading may be completed. For gravity lines 1–5, a minimum pressure of 120 p.s.i. is obligatory for the last 1500 tons of cargo, and for gravity lines 6–8, a minimum pressure of 130 p.s.i. is required for the last 2000 tons of cargo. After loading has been completed and the loading valves at the ship's side closed, the whole of the loading system from there through to the tank or tanks in the Ahmadi tank farm are left open for a minimum of 20 minutes from the completion of loading. This being done to ensure accuracy in the final dip of the tank used for loading. Appreciable surging takes place at the time of shutting off of the loading valves at the ship's side, and the delay in taking final dips is to allow static conditions to be re-established.

MANPOWER REQUIREMENTS

The operational aids which have been provided are designed not only to enable ships to be loaded and despatched with the greatest expediency, but also to allow this to be done with minimum manpower requirements. In March 1955, 243 crude oil cargoes were completed and despatched. As far as terminal and tank farm staff were concerned (but excluding marine staff), 132 men were employed in these operations, the vast majority of whom are employed on shift duties round the clock. Of special interest is the chief loading co-ordinator, and under his control four loading co-ordinators, who work on a shift basis. These men, as their designation suggests, use all means at their disposal to reduce the overall berth time occupied by vessels using the terminal. Their duties involve keeping an up-to-the-minute assessment of loading and bunkering operations to enable the fullest use to be made of the crude and bunkering facilities. Their primary objective is the optimum use of the gravity line and loading systems. Liaison is maintained with the marine operations department, providing an up-to-the-minute picture of loading operations so that vessels awaiting berth may be alerted to be ready for earlier berthing if a speeded up turn around of vessels already in berth can be achieved.

TANKER TIME ANALYSIS RECORDS

In order to effect the maximum stream-lining of crude loading operations, a number of the oil companies operating crude terminals in the Persian Gulf, in the Mediterranean, in the U.S.A., and in Venezuela



SWITCHGATE CONTROL MANIFOLD—GENERAL VIEW CONTROL ROOM

maintain records of all the operations, direct loading or otherwise, connected with oil shipments. In essentials, it is a time study of all those operations connected with loading split into easily recognizable simple operations. An outstanding merit of this tanker time

TABLE VI

Tanker Operational Times, 1946–51

Number of Vessels	1946 61	1947 168	1948 436	1949 802	1950 973	1951 1693
	hr min	hr min	hr min	hr min	hr min	hr min
Arrival in port to arrival at berth .	24 08	17 35	19 45	16 06	5 19	24 —
Arrival at berth to commence discharging ballast .	1 15	1 50	1 04	— 34	— 14	— 12
Discharging ballast .	6 55	5 50	4 50	4 50	5 9	5 4
Finish ballast to commence loading	2 23	1 40	1 12	— 51	— 31	— 38
Loading time .	14 34	15 30	15 49	14 37	11 25	10 23
Completion loading to sailing . .	6 17	4 35	4 47	3 51	2 55	3 7
Time in berth .	31 24	29 5	27 42	24 43	20 14	19 24
Time in port . .	55 32	46 40	47 27	40 49	25 33	43 24
Average cargo loaded:						
tons . . .	12,604	12,581	14,323	14,975	16,235	15,725
brl . . .	—	93,703	105,960	110,528	119,934	115,969
Average loading rate:						
tons/hr . .	865	838	936	1,019	1,504	1,583
brl/hr . .	—	6,241	6,926	7,540	11,130	11,714

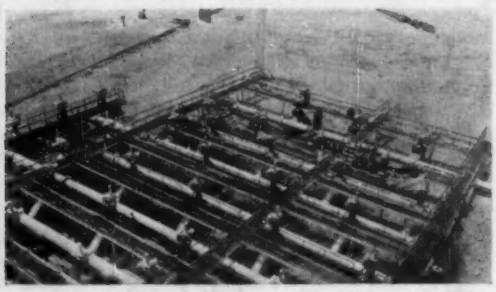
TABLE VII

Abbreviated Tanker Time Analysis Records, 1952–55

	June 1952	Sept. 1952	Average 1952	Sept. 1953	Average 1953	Average 1954		February 1955	
						Jetty	Crude submarine *	Jetty	Crude submarine
Number of ships	183	187	185	197	204	199	10	199	11
Operational Times :	hr min	hr min	hr min	hr min	hr min	hr min	hr min	hr min	hr min
(1) Time between notice of readiness and departure from anchorage	11 12	2 48	4 49	0 27	4 09	6 44	3 52	11 28	4 55
(2) Time between departure from anchorage and arrival at berth	— 49	— 47	— 48	— 45	— 45	— 45	— 54	— 47	— 46
(3) Time to deballast from arrival at berth	5 35	5 30	5 46	5 21	5 38	5 23	5 25	5 24	5 28
(4) Time from completion of deballasting to tank inspection	— 09	— 08	— 08	— 08	— 08	— 08	— 08	09	— 08
(5) Time from tank inspection to commence loading	1 26	— 32	— 36	— 21	— 24	— 28	— 58	— 24	1 01
(6) Total time to load	11 07	10 43	10 43	10 18	10 20	10 55	11 26	11 —	11 06
(7) Time from completion of loading departure from berth	1 33	1 39	1 35	1 27	1 38	1 34	2 38	1 39	2 24
(8) Time from departure from berth to sailing	3 35	— 32	1 05	— 32	— 32	— 32	— 15	— 40	— 02
(9) Total time in port	38 44	22 38	25 30	19 17	23 33	26 27	25 37	31 31	25 51
(10) Total time between completion of loading to documents signed	3 24	1 55	2 15	1 46	1 48	1 47	2 14	1 56	2 08
(11) Total time in berth	19 51	18 31	18 48	17 33	18 07	18 28	20 31	18 36	20 08
Delays									
(1) Weather delay	1 22	Nil	— 25	— 04	— 36	1 14	1 02	1 30	— 45
(2) Awaiting berth	10 06	2 48	4 24	— 23	3 32	5 30	2 50	9 58	4 10
(3) Ship's purposes	3 07	— 10	— 08	— 06	— 06	— 07	— 06	— 07	— 10
(4) Awaiting cargo or loading system	1 15	— 14	— 20	— 08	— 08	— 14	— 39	— 11	— 40
(5) Awaiting bunkers	— 03	— 04	— 02	— 03	— 11	— 05	— 18	— 07	Nil
(6) Miscellaneous	— 40	— 24	— 36	— 11	— 20	— 24	— 34	— 11	— 53
Cargo and Loading Details									
(*a*) Net cargo loaded :									
tons	16,031	15,994	16,207	17,333	16,890	18,363	14,861	19,009	14,388
brl	118,117	117,927	119,568	127,816	124,714	135,782	110,083	140,826	106,763
(*b*) Net loading rate :									
tons/hr	1,488	1,523	1,561	1,709	1,635	1,732	1,356	1,751	1,384
brl/hr	10,999	11,241	11,519	12,602	12,298	12,803	10,053	12,970	10,272

* Excluding January and February.

analysis is that it enables "bottle-necks" to be easily discernible and remedial action to be taken if there is an economic justification for it.



SWITCHGATE CONTROL MANIFOLD—GENERAL VIEW

The more important operational times and details of loading operations have been maintained from the start of exports from Kuwait in June 1946, and more detailed spot analyses have also been carried out from time to time since then. This has especially applied at times when the port was operating at peak capacity, for example, in April and July of 1951. Detailed systematic analyses were not, however, introduced until March 1952.

In preparing the tanker time analysis, the relevant operational times and details and delays are tabulated for each berth. A typical month's record is shown in Table IV. The individual berth analysis are consolidated into a final analysis, as shown in Table V. The analyses are divided into three sections : (*a*) operational times; (*b*) loading details; and (*c*) delays incurred.

(a) *Operational Times*

Column 2 shows arrival time, and

Column 3 notice of readiness to load. Any difference between these two times will be ship's responsibility, *i.e.* requiring engine repairs prior to loading.

Column 4 shows time between notice of readiness and departure from anchorage. This could cover a number of contingencies, *e.g.* unfavourable weather and sea conditions, berth unavailable as a result of shipping congestion, or during hours of darkness (this would apply only on rare occasions and only to inside berths).

TABLE VIII

Loading Rates v. *Time to Load*

Year	Maximum loading rate tons/hr	Minimum loading rate tons/hr	Average loading rate tons/hr	Average time to load	
				hr	min
1946	1,153	511	865	14	34
1947	1,125	413	838	15	30
1948	1,266	510	936	15	49
1949	3,078	312	1,019	14	37
1950	3,636	549	1,504	11	25
1951	3,856	422	1,583	10	23
1952	3,959	245	1,519	10	54
1953	—	—	1,635	10	20
1954	—	—	1,732	10	55

Column 5 shows time between departure from anchorage and arrival at berth. This is a reasonably constant time, and would only vary from the average appreciably if a vessel anchored well away from the oil pier precincts.

Column 6 shows time of deballasting from arrival at berth. This is largely a ships' matter and outside the control of the terminal personnel, although normally a minimum ballast quantity is insisted on, according to the size of the vessel, to avoid possible damage to the jetty structure during berthing operations. There are wide variations in the deballasting times, and usually the older vessels using the terminal are responsible for the greatest delays prior to loading from this cause. At something over 5 hr per ship, it represents the major non-useful time during berth occupancy.

Column 7 shows time from completion of deballasting to tanks inspected, and should normally not exceed 10 minutes.

Column 8 shows time between tanks inspected and commencement of loading. Times occupied under this heading are normally a ship's responsibility, and would include such operations as tightening down tank lids and lining up operations aboard. Abnormally high timings under this heading occur as a result of a ship advancing unduly her time to commence loading, and also when the shore loading system is unavailable.

Column 9 shows total time to load. This is a factor which is influenced by the size of the vessel, the rates at which the master is prepared to load, and the loading rates which the terminal can provide. These factors are described in greater detail in a later section of the present paper.

Column 10 shows time from completion of loading to departure from berth. Time occupied under this heading is for disconnecting of loading and bunkering hoses and unmooring operations. The variations from the average time can occur when the port is operating at less than full capacity, because in these circumstances a net saving in ship's time is accomplished by having ship's papers signed while the vessel is alongside rather than proceeding to the anchorage while waiting for this to be done.

Column 11 shows total time in berth. This is the sum of columns 5, 6, 7, 8, 9, and 10. As a generalization, it is interesting to note that of the total berth time, approx only 60 per cent is used in actual loading operations, the remaining 40 per cent being used for operations other than direct loading, and that of this 40 per cent approx 65 per cent is in deballasting time.

Column 12 shows the time from departure from berth to completion of documents. Only positive timings under this heading occur when ship's papers are not signed alongside the loading berth and when the vessel requires to anchor after leaving berth.

Column 13 shows total time in port from notice of loading to departure from berth or documents signed. This factor represents the total time in port, including anchor time.

Column 14 shows time between completion of loading to documents signed. Every effort is made here to have documents signed prior to the vessel leaving berth, but at times of full berth occupancy it is the exception rather than the rule for ship's papers to be signed alongside, since it is almost always possible to complete unmooring operations before ship's papers can be prepared.

(b) *Loading Details*

Columns 15 *and* 17 show net barrels and net tons loaded.

Columns 16 and 18 show the overall average loading rate in brl/hr and tons/hr, and takes into account the slowing down in loading rates at the conclusion of loading as required by terminal operational instructions, and in many cases to meet ship's requirements during tank topping up operations.

Column 19 shows loading rate requested in tons/hr. This figure is the maximum rate at which the vessel will receive cargo and will in these circumstances, even if the rate is available, be in excess of the actual average loading rate achieved.

Column 20 shows the loading rate which the terminal facilities could provide, and will vary according to the gravity line or combination of gravity lines which were available for the particular berth at which the ship was tied up.

Columns 21, 22, *and* 23 are for record purposes only and for providing statistical data when carrying out studies connected with loading operations.

(c) *Delays Incurred*

Column 24 shows hours delayed owing to weather. Under this heading only delays are recorded when berthing operations are actually suspended.

Column 25 shows hours delay, berthing operations. Delays under this heading would include those incurred by vessels held up as a result of weather delays from the time that berthing is resumed after unfavourable weather. Also delays resulting from shipping congestion under normal bunching conditions, and delays during hours of darkness when inside berths are not used.

Column 26 shows delays for ships' purposes, and covers a number of widely varying factors.

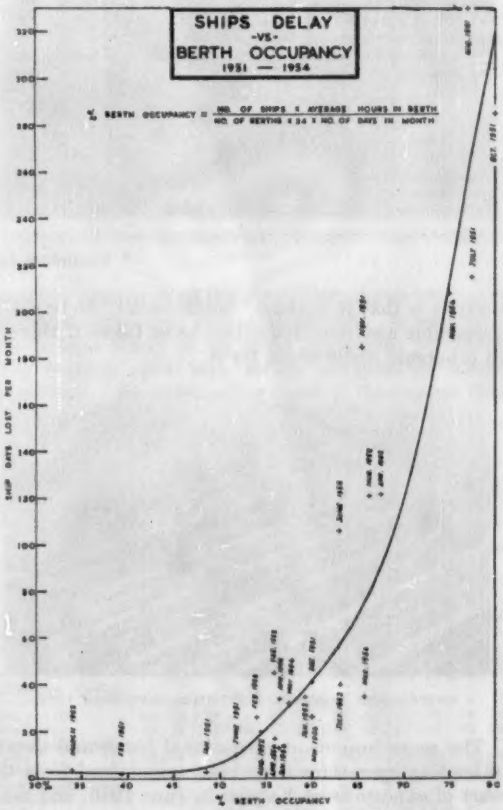

SHIPS DELAY
-VS-
BERTH OCCUPANCY
1951 — 1954
% BERTH OCCUPANCY = NO. OF SHIPS × AVERAGE HOURS IN BERTH / NO. OF BERTHS × 24 × NO. OF DAYS IN MONTH
SHIP DAYS LOST PER MONTH
% BERTH OCCUPANCY

FIG 3

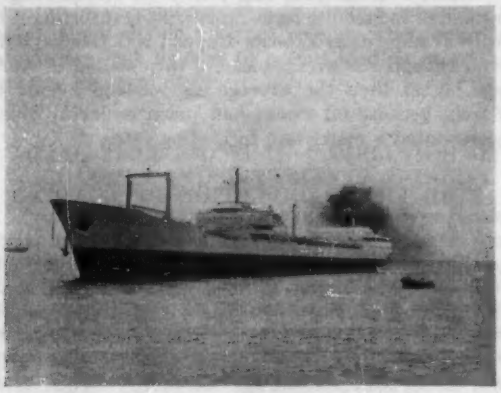
Column 27 shows delays awaiting loading system. This is an entirely terminal delay associated with, for example, a ship unduly advancing her readiness to load after berthing. It is most frequently incurred after a period of heavy loading when oil stocks have been denuded as a result of the differential between all-out terminal loading capacity and all-out pumping capacity from the field areas.

Column 28 shows delays awaiting bunkers. Delays under this heading have been largely eliminated since the installation of meters at individual berths for varying oil bunker deliveries.

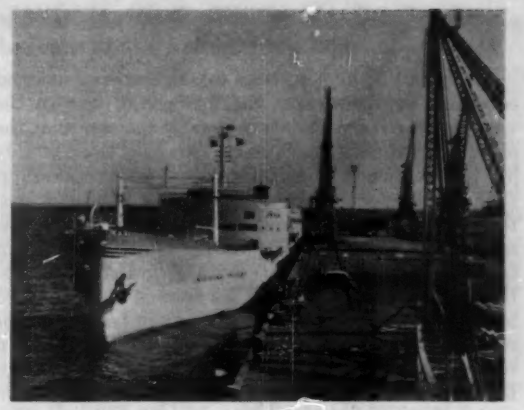
Column 29 shows miscellaneous delays, and is used for contingencies not covered by the other headings.

A final remarks column is used to amplify abnormal timings and delays, and is especially useful in providing information should queries be raised in connexion with loadings after some time has elapsed.

Table VI shows tanker operational times during the period 1946–51. During 1946–48, and until November 1949, all loading operations were carried out at submarine loading berths. Of special interest in studying the tanker operational times during this period is the abnormally high times between " arrival in port " to " arrival at berth." This is largely accounted for by the fact that no night berthing occurred during this time, and by the fact that tidal conditions made it necessary to wait for the appropriate berth (ebb or flood), even during daylight hours. Loading times were all in excess of 14 hr per ship, mainly because the terminal had not the necessary maximum loading capacity, nor were vessels in many cases capable of loading at higher rates than those available. Even by 1949, the average loading rate was only just over 1000 tons/hr. With the commissioning of the oil pier in November 1949, a very marked improvement immediately resulted (even though night berthing was not introduced until some time afterwards) in loading rates and total time in berth, and total time in port. This is shown in the 1950 and 1951 records in Table VI. Time from arrival in port to arrival at berth dropped sharply to a little over 5 hr per ship. (This timing rose to 24 hr per ship in 1951, but this was as a result of a very heavy shipping congestion resulting from the closing down of operations in Persia.) Average loading rates rose by 50 per cent to over 1500 tons/hr. This improvement partly resulted from an improvement in shore terminal capacity, and also by an increase in the numbers of larger vessels capable of loading at higher rates. Total time in berth dropped by almost 50 per cent, and total time in port by almost 100 per cent, despite the fact that the average cargo lifted had risen from something over 90,000 brl to almost 120,000 brl per shipment.



SS " TINA ONASSIS " APPROACHING TERMINAL BERTH



CARGO PIER, SHOWING SWEDISH TANKER " JOSEFINA THORDEN " ALONGSIDE

Table VII shows abbreviated records abstracted from the more comprehensive tanker time analysis records which were maintained from March 1952, and these are now discussed in detail.

TIMES BETWEEN NOTICE OF READINESS AND DEPARTURE FROM ANCHORAGE

This is a factor over which there is no real control, and largely dependent on the weather conditions prevailing. The influence of normal " bunching " associated with any major loading port has a relatively slight effect, and the major one is the effect of unfavourable weather. If the two factors coincide, however, heavy delays will be incurred. It is interesting to compare the June 1952 times under this heading with those for September 1953, largely because of a delay of 11 hr 12 minutes resulting from unfavourable weather and " bunching." The total time in port for 183 vessels averaged 38 hr 44 minutes. In September 1953, time between notice of readiness and departure from anchorage for 197 vessels was only 27 minutes, with the result that the total time in port for these vessels averaged only 19 hr 17 minutes.

TIME BETWEEN DEPARTURE FROM ANCHORAGE AND ARRIVAL AT BERTH

Average timings under this heading show little variation from month to month or from year to year, and little can be done to improve the time of approximately 45 minutes for this operation.

TIME OF DEBALLASTING FROM ARRIVAL AT BERTH

At around 5½ hr per vessel this figure has remained constant, irrespective of the increase of size of the vessels using the port. It is usually the case that the older and smaller, the vessels carrying considerably less ballast occupy more time in deballasting operations than the modern larger vessels. It is apparent that the deballasting operations represent a very appreciable non-useful berth time. One of the major independent tanker owners had a completely segregated ballast system installed in a number of his vessels, which enabled loading to be started as soon as loading hoses could be connected up. The most recently built vessels in this tanker fleet have, however, reverted to normal practice for ballast arrangements, presumably because present tanker freight rates do not justify the additional expenditure for a segregated deballasting system.

TIME FROM COMPLETION OF DEBALLASTING TO TANK INSPECTION

No special comment on this timing, which has remained uniformly low at just under 10 minutes.

TIME FROM TANK INSPECTION TO COMMENCE LOADING

Every effort is naturally made to reduce this time to a minimum, and over a normal year's operation averaged something of the order of 30 minutes. Causes of abnormal timings have already been discussed.

TOTAL TIME TO LOAD

This important factor is largely dependent on: (*a*) the maximum rate at which the master of the vessel is prepared to load cargo (in general the size of the vessel and its age will be a contributory factor, and will be discussed below), and (*b*) the loading capacity of the terminal facilities.

Table VIII shows maximum and minimum loading rates and also the average loading rate for the period 1946–54. It will be seen that the average loading rate per vessel has almost exactly doubled during this period, whereas there has been an approaching 50 per cent reduction in the total time to load. Both the factors mentioned above have contributed to enable these figures to be achieved. Up to the end of 1951 the maximum loading capacity on a single gravity line system was about 1750 tons/hr (although by using combinations of gravity lines and loading lines, rates of up to 4000 tons/hr could be achieved), and at this time, as a generalization, approx 50 per cent of vessels were willing to accept loading rates in excess of those available at peak loading capacity, whereas the remaining 50 per cent of vessels loading were not prepared to accept maximum rates available.

While the commissioning of the 30-inch gravity line (capacity 2450–3000 tons/hr) at the end of 1951, and in 1952 of a 34-inch gravity line (capacity 2700–3000 tons/hr) and a combination 30–34-inch gravity line (capacity 2300–2700 tons/hr), there became available three high loading capacity systems, with the result that the loading rates requested by a large proportion of vessels now loading can be met. This, perhaps, needs qualification in that it is not always possible, even allowing for a large degree of flexibility available, to have the high loading capacity vessels berthed in such a way that the highest capacity loading systems are available to them.

One very important factor influencing loading rates is the crude oil available for export. It is only possible to consistently achieve maximum loading rates when operating with high oil stocks, *i.e.* at least 50 per cent of the Ahmadi tank farm capacity.

This has been very clearly illustrated during March and April of 1955. As a result of an abnormally long spell of unfavourable weather in mid-March, associated with what was in any case an extremely heavy export programme, there has been a congestion in the loading port of up to between forty and fifty ships awaiting berth. When loading was resumed, it was possible to sustain peak loadings over a prolonged period. During the last fortnight of March exports averaged 1,265,000 b.d. During this period oil stocks ranged from high to medium levels. For the first fortnight in April average daily exports dropped to 1,160,000 b.d., even though the average size of ship loaded in April was higher than the average size of ship loaded in March, because oil stocks had fallen to levels which necessitated a restriction in loading rates.

TIME FROM COMPLETION OF LOADING TO DEPARTURE FROM BERTH

This time has, since 1952, shown little variation from just under 1 hr 40 minutes, and is normally, when the port is operating at peak capacity, the minimum time required for disconnecting, loading, and bunkering hoses, taking of ship's ullages, and unmooring operations. As is stated earlier, however, when the berth is not immediately required, either because no ship is waiting or alternatively the berth is inaccessible because of neighbouring vessels, it is normal practice to allow the vessel to remain alongside until documents can be completed, thus effecting a net gain in ship's time.

TOTAL TIME IN PORT

This time probably shows more variation than any other recorded in tanker time analyses, varying widely from month to month, and showing appreciable differences from year to year. For example, in June 1952, total time in port was 38 hr 44 minutes, in September 1953 it was 19 hr 17 minutes. The average for 1953 was 23 hr 33 minutes, while in 1954 it was 26 hr 27 minutes. By far the greatest contributory factor causing variations in time in port is the weather delay, and delays awaiting berth, almost always

associated with unfavourable weather. Experience has shown that high total times in port have always been associated with high berth occupancy, and during the period from January 1951 to August 1952, statistics were compiled showing ships' days lost per month against percentage berth occupancy.

Berth occupancy is defined as :

$$\frac{\text{No. ships} \times \text{Average hours in berth}}{\text{No. berths} \times 24 \times \text{No. days in month}}$$

In Fig 3 percentage berth occupancy has been plotted against ship days lost per month in 1951 and 1952, and also during the period January 1954 to January 1955. The graph clearly indicates that little ships' time is lost at berth occupancy up to 55 per cent. The curve starts to slope steeply at about 60 per cent, and at 70 per cent berth occupancy very heavy ships' lost time is incurred. It will be noted that during 1954 the ships' lost time for berth occupancies below 70 per cent fall below the curve appropriate on the basis of 1951–52 loading operations. The reason for this was that in 1954 from March onwards additional submarine berths were available to partially relieve the load on the jetty. The use of the submarine berths has, however, been intermittent, in that their use can be justified only if it results in a net saving in ships' time, and this is only possible when crude oil stocks are high enough to permit loading at normal gravity line capacity.

TOTAL TIME BETWEEN COMPLETION OF LOADING AND DOCUMENTS SIGNED

Prior to comprehensive tanker time analysis records being maintained, the time for documents to be completed, i.e. signed on board after completion of loading, was high, averaging 3 hr 24 minutes in June 1952. Steps were taken to reduce this time by providing office accommodation for documents' staff on the oil pier, and by using the "Loading Co-ordinators" to speed up the flow of relevant data required for the completion of documents. By September 1952, documents time had been reduced to 1 hr 55 minutes, and although the average for 1952 was 2 hr 15 minutes, since then the yearly averages have been between 1 hr 45 minutes and 2 hrs.

Under the most favourable conditions, documents times of less than 1 hr have been achieved, but this is dependent on several factors, such as relatively small documentary requirements, relatively even loading completion programme (it sometimes happens that up to four to five ships may complete loading inside 30 minutes, this inevitably prolongs documents time), and the port condition permitting documents to be placed aboard while the vessel is still alongside.

Factors not mentioned previously which contribute to abnormally high documents times are exceedingly heavy documentary requirements for shipments to certain countries, and the master's pre-occupation during unberthing operations. It is not anticipated that any marked improvement in documents time can be achieved under present conditions.

TOTAL TIME IN BERTH

Timings under this heading have remained fairly constant during the period 1952–55 at between 18 and 19 hr, despite the fact that the average cargo loaded has risen from just over 16,000 tons to almost 19,000 tons, the reason being that terminal loading capacity has been stepped up to at least match the increase in ships' sizes, and that masters of the larger vessels are prepared to accept higher loading rates. The size of ship loaded plays a most important part in determining the port capacity, since of a total time in port of between 18 and 19 hr, only between 10 and 11 hr are used in direct loading. As far as the terminal is concerned, only about 60 per cent of berth time is usefully employed. As a generalization, the non-loading berth time remains more or less constant, irrespective of the size of vessel, and there is no doubt, with all other conditions being equal, that the increases in size of vessels appreciably up-grades the loading port capacity.

Table IX shows size of tanker and time to load.

TABLE IX

Size of Tanker v. *Time to Load*, 1946–54

Year	Largest cargo loaded, tons	Smallest cargo loaded, tons	Average cargo loaded, tons	Time to load	
				hr	min
1946	15,848	8,213	12,604	14	34
1947	17,034	5,484	12,581	15	30
1948	26,281	7,775	14,323	15	49
1949	29,267	7,614	14,975	14	37
1950	29,125	7,601	16,235	11	25
1951	29,200	5,042	15,725	10	23
1952	30,964	4,677	15,920	10	54
1953	35,433	6,525	16,880	10	20
1954	39,696	8,458	18,239	10	55

Table X shows a break-down of ship's sizes loading at the Mina-al-Ahmadi terminal during the period 1951–54. It is of considerable interest that the under 10,000-ton ship in 1954 has fallen to less than three per month. The over 20,000 tonner has increased from twenty-five per month in 1951 to nearly sixty per month in 1954.

By reason of the geographical location of the Mina terminal it can reasonably be anticipated that further

TABLE X

Size of Tanker by Tonnage

Year	Under 10,000 tons	10,000–14,500 tons	14,501–20,000 tons	Over 20,000 tons	Total
1951	138	546	716	293	1,693
1952	118	771	968	390	2,247
1953	69	665	1,188	513	2,435
1954	33	500	1,251	713	2,497

substantial increases in the numbers of large, fast-loading vessels using the port can be expected. Provided matching production and pumping facilities are provided, existing terminal facilities are capable of still further increases in loading capacity.

CONCLUSIONS

The following are essential requirements for a major crude oil loading terminal to ensure maximum output with minimum delays:

(1) Field production and pumping facilities to at least equal maximum port loading facilities.

(2) If the conditions in (1) cannot be met, sufficient tankage should be provided to enable oil stocks to nullify any differential between loading capacity and production and pumping capacity from the field areas.

(3) The provision of the maximum automatic and remote control which is economically justified on the basis of: (*a*) achieving the best tanker turn around, with (*b*) the minimum of manpower.

(4) The maintenance of operational records to enable bottle-necks in loading operations to be easily discernible and remedied where economical justification can be provided.

ACKNOWLEDGMENTS

The author thanks the management of the Kuwait Oil Co. Ltd., for permission to publish this paper, and his colleagues in London and Kuwait for their advice and assistance in its preparation.

DISCUSSION

J. M. Jefferies: Mr Dougary has collated an enormous amount of detail data, and I sometimes think people imagine that this is collected merely to be lost on files. The paper demonstrates adequately that in this case it is not so, because without much of this information, tankage, loading lines, and the organization would not have been available in time to meet the extremely rapid growth in the tonnage of oil shipped from Kuwait during the past six or seven years.

It is now many years since I was directly concerned with loading crude vessels, but with the advent of the large refineries in the U.K., I have been concerned with imports of Kuwait crude, which form a major part of refinery operations. But even as long ago as the early thirties we were loading in Venezuela, small lake tankers, at about 1500–2000 tons/hr. Unfortunately, these loading rates had to be reduced because of foaming in the ships' tanks. I would like to know whether this phenomenon has been experienced in Mina-al-Ahmadi, and if so, how has it been overcome?

Another subject which has been much discussed by my company, is the build-up of waxy sludge in ships and shore tanks. After very careful investigations, we decided that by not allowing the temperature of the crude to fall below 85° F whilst in transit, the sludge deposit was considerably reduced, if not eliminated in ships' tanks. I presume it is because of the very short residence time the crude remains in storage at Mina-al-Ahmadi that this is not a major problem there. However, I would ask Mr Dougary to confirm whether this assumption is correct, and if not, what do they do with the sludge. Are tank bottoms being shipped as crude?

With shipments of Kuwait crude approaching the million tons per week mark, I am surprised that the tankage capacity in Mina-al-Ahmadi is not more than 600,000 tons, or only about four days storage. Is this the total available, or is the Mina-al-Ahmadi tankage only for shipping purposes with further storage back in the fields.

Remote liquid level indicators are becoming more generally used, especially on off-site facilities at refineries, and although the author does not say so, I presume that high and low level alarms are used at Mina-al-Ahmadi. My company would consider that with such a high rate of in-take and off-take to and from the tanks, that this device was essential. The first major mishap would condemn liquid level gauges for a very long time, especially with Customs authorities. What is novel, although I cannot say much about them, is electrically remote-controlled valves installed on crude storage tanks and ancillary pipelines. Without a doubt, this is a facility which must be appreciated by the personnel who are actually responsible for setting the valves, especially under a tropical sun. However, I feel that it is only at loading ports such as Mina-al-Ahmadi, where a very large volume of crude is handled, that such a system is justified.

Mr Dougary has laid considerable emphasis on berth occupancy and tanker turn round, and has given a lot of statistical detail. In the event of extra berthing capacity being required, say, at the loading pier, would additional loading lines and tanks also be installed? The actual time the existing loading lines are used is no more than 60 per cent of the useful time the ship is in berth, and it therefore appears that there is a case for extra berths without necessarily increasing the number of loading lines or tanks.

It may not be long before positive displacement meters, either used singly or in parallel, are available for high rates for rolling crude cargoes. After noting the accuracy of the figures given—they are better than one-tenth of one per cent for the deliveries of heavy fuel as bunkers—I feel that many meter manufacturers will be encouraged to meet the demand for this equipment. Such meters would certainly cut down capital expenditure on storage tanks and shipping lines, and also considerably reduce the time taken to prepare loading documents.

Referring to Mr Dougary's conclusions, I would ask him to clarify Item 1. To say that production and transfer rates on the field must at least equal loading rates, is to put the cart before the horse. Surely, at no time must production be restricted because of the lack of loading facilities. I suggest that the loading rate should be at least 50 per cent greater than the rate of production.

It is the considered view of those in the know, that the world demand for energy will be doubled in the next few years. Coal production is said to have reached its peak and may decline. Atomic energy and hydro-electric schemes are not likely to make any great impact during this time. The burden will therefore fall upon petroleum products. It would be interesting to know if the Kuwait facilities are being scaled up to meet this ever increasing demand for energy.

J. M. Dougary: Mr Jefferies raised seven points. The first referred to foaming taking place at tanker loading rates of 2000 tons/hr in operations he was connected with in Venezuela. This is something that we have not experienced in any way in our operations at Mina-al-Ahmadi. Although rates of over 400 tons/hr have not been infrequent, there have been no complaints or evidence of foaming occurring. Whether this is owing to the characteristics of Kuwait crude or the difference in design between the modern tank vessels and the shallow draft tankers which were in use in Venezuela I am not in a position to say.

The second point—sludge build-up. No, sir, we do not ship sludge as crude. (Laughter.) All our crude export tankage is fitted with a baffle 2 ft 6 inches high inside the tank at the outlet nozzle so that at least 2 ft 6 inches of sludge would have to be built up before there was any chance of sludge being shipped along with the crude. (Tests carried out on all our crude cargoes have shown a maximum B.S. & W. of 0·2 per cent.) As Mr Jefferies has said, the reason why we do not have any trouble with sludge build up is mainly that the oil has a very small residence time and minimum crude oil temperatures are normally in excess of 60° F. In this connexion, my General Manager never refers to our export tanks as "storage tanks" but as "operational tanks." Despite what I have said, there is a build up of sludge in our export tankage over the years, but it is extremely slow, probably of the order of 1–2 inches p.a. Only now has it been found necessary to desludge the tanks which were erected and commissioned ten years ago, the sludge levels having risen from 1 ft 10 inches to 2 ft, still some 6 inches below the level of the baffle.

I have partially answered Mr Jefferies question about tankage in my preceding comment. Our tankage is not regarded as storage but as operational tankage. Thus, we have the minimum tankage that can reasonably be expected to handle the export rates required. Mr Jefferies is quite right, we have only a very little over four days capacity at all-out rates from the field, from completely empty to completely full. Taking into account unavailable bottoms, *i.e.* below the floating roofs at point of grounding, tanks that are filling from the field and in export operations, we do not have much more than one to two days actual operating space. Apart from the export tankage, we have a little additional storage in the field areas at the individual gathering centres, this probably amounts to 600,000–700,000 brl, in all, spread over ten gathering centres, and is used only in an emergency.

The fourth point Mr Jefferies raised concerns high and low level alarms for the liquid level gauges. These have, in fact, been provided on some, but not all of the liquid level gauges. I do not know whether it is that the operational men have been very much "on the ball," but in the whole of our ten years of operations there has been only one case, and this only a slight one, of a tank over-flow. It was spotted immediately and remedial action taken. Our present thoughts are, however, that at the very high export rates now being made we should be well advised to have our tankage fitted with high and low level alarms on the liquid level gauges, and this is planned.

Mr Jefferies asked whether it would be necessary to provide additional tankage and additional gravity lines if the scale of exports called for extra berths. The answer is probably yes. Although only 60 per cent of ship's time is used in direct loading operations while it is alongside, I mentioned that when other ships alongside were engaged in non-direct loading operations, *e.g.* such as deballasting, those ships actually loading cargo are capable of loading at rates in excess of a single gravity line–loading line system, then a second or third system is added with the result that we can get up to 90 per cent gravity line utilization.

In regard to production facilities *v.* loading rates, Mr Jefferies said I had put the cart before the horse. I do not think I have. Just as long as one's port loading capacity is higher than one's maximum production rates from the field, a heavy accumulation of shipping is going to gradually bring down the oil levels in the tankage, thereby resulting in slowing down of loading rates (and aggravating the shipping congestion). One gets involved in premature switching of the filling tanks and the same thing on the tanks being used for export, which makes a lot of additional work for the operational staff. At present, our production and pumping facilities are very nearly in line with maximum sustainable loading rates, although not quite. Therefore, if we have a very long high loading period our storage levels are brought down to the extent that loading operations are slowed down. I say, then, that if one's production facilities are not equal to maximum loading rates one has to provide sufficient tankage to enable loading to continue at higher rates for an appreciable time, *i.e.* of the order of from ten to fourteen days at higher rates than oil is coming in from the field areas.

The final point Mr Jefferies raised concerns plans for increasing crude oil handling facilities in Kuwait. I am afraid all I can say in that connexion is that in the past our Management has provided facilities to take care of export requirements, and I have no doubt that they will continue to do so in the future.

L. J. Shrubsall: May I ask Mr Dougary if there is any special technique for the emptying of hoses before disconnecting after loading? And also whether there is any special snap coupling between ship and shore for emergency release in any way?

J. M. Dougary: On the first of the two points Mr Shrubsall raised, a compressed-air connexion is provided on the down-stream side of the loading valve on the jetty at the ship's side which is used to dispose of the small quantities of crude remaining in the loading hoses at the conclusion of loading.

On the second point, as a normal rule, loading hoses are connected to the ship's connexions by bolted connexions. In the event of unfavourable weather, however, clamps are bolted on which can be snapped off at very short notice if so required.

C. E. Blackman: I would like to ask Mr Dougary if there is any means of temperature compensation on the meters, and, if not, how do they overcome the problem of varying temperatures?

J. M. Dougary: The Brodie positive displacement meter is not fitted with a temperature compensator as the Smith meter is. We use a temperature recorder located in the immediate vicinity of the meter within a few feet of pipeline from it. The recorder is in use throughout the course of the bunker delivery, so that any slight changes in temperature during the course of the delivery can be averaged out to enable the necessary temperature correction to be made. Adjacent to the thermowell for the temperature recorder is a second thermowell to enable periodic checking of the temperature recorder with a NPL thermometer.

A. C. Poore: Would Mr Dougary please tell us a little more about the topping up operations on tankers? He refers to 60 per cent of the berth time being for loading and, at the very high loading rates, does he know if any great proportion of that loading time is occupied in topping up? Otherwise, it seems to me there is a possible danger of a vessel being slightly overloaded. If that does ever arise, then there are all sorts of complications for the possible return to shore of the surplus.

J. M. Dougary: On p. 12 of the paper, figures are given for the minimum loading pressures required to be maintained at the last stages of loading. For gravity

lines 1–5 a minimum pressure of 120 p.s.i. is required for the last 1500 tons of cargo, and for gravity lines 6–8 a minimum pressure of 130 p.s.i. is required for the last 2000 tons. This in practice means that for approx 1–1½ hr, loading rates are cut back to avoid any possibility of line drainage and, at the same time, this enables topping up operations aboard the vessel to be carried out smoothly. It is very difficult to generalize because most chief officers responsible for handling the loading have different techniques. Some will load for a few hours only at maximum rates and then cut back progressively. All ships are cut back during the topping up operations, from approx 1 to 1½ hr before loading is completed.

A. C. Poore: Has there ever been difficulty with ships being overloaded? If so, that is perhaps leaving such considerations a little late.

J. M. Dougary: I can recall no instances of a ship actually taking more cargo than was wanted as a direct result of high loading rates. There have been difficulties as a result of not knowing the exact amount of the cargo to be loaded. This most frequently arising when ships load to draft, which is not always easy to read at times of rough weather. As far as I can recall, there have been no instances of overloading because of loading rates being sustained at too high levels too near to the conclusion of loading.

G. Heseldin: I am rather disappointed Mr Dougary did not mention Umm Said in Qatar as one of the crude oil loading ports of the Persian Gulf, and the fact that they also have the large 164-ft dia tanks there.

I would like to ask if any special precautions were taken in the design, to prevent the rupture of the large 30-inch dia pipelines from the tank farm to the jetty, with the 300-ft difference in elevation, in the event of the sudden closing of a valve at the jetty end, and whether they have had any troubles on this account?

Are there bunkering facilities at the sea loading berths at Mina-al-Ahmadi? And if so, do they have undue hose trouble, by having possibly three to five hoses at the berth, which would be required to load crude and supply the different kinds of bunker fuels?

J. M. Dougary: Protection has been provided to avoid high surge pressures which can develop if the loading lines can be shut off quickly. I do not know if Mr Heseldin recalls the layout of the jetty. In the middle of it we have got expansion loops to take care of the pipeline expansion and contraction. On top of these, one per line, we have 2-inch pressure relief valves set at 275 p.s.i., and in the event of pressure exceeding this the relief valves would open. At the switchgate control manifold, we have another set of relief valves on each of the loading lines, these being set at 250 p.s.i. Loading procedure calls for the loading valves to be shut off at such a rate that the line pressure does not exceed 200 p.s.i. In the event of the valve being shut at too fast a rate, protection is provided first at the switchgate manifold and then at 275 lb at the expansion loops on the jetty. In fact, at the rates which loading is carried out it is extremely difficult to shut the loading valves too quickly, and we do not regard the development of high surge pressures as being a particularly dangerous one.

The second point Mr Heseldin raised was in regard to bunkering facilities at the sea loading berths. Of three berths normally used for crude oil loading, two are provided with B.F.O. bunkering facilities and one with marine diesel bunkering facilities. Each berth has a 24-inch submarine line terminating in a single 12–10-inch crude loading hose, and a 12-inch bunkering line ending in an 8-inch bunkering hose. We therefore, have no trouble with loading hoses becoming entangled. Even so, the performance of the crude and bunkering hoses has not altogether been satisfactory and there have been more failures even during the limited times the submarine berths have been used than we consider reasonable.

A. F. Dabell: Is any provision made for a crisis whereby shipments are arrested? Also, what is the cause of waxy sludge in ships and shore tanks?

J. M. Dougary: The waxing in ships' tanks is generally associated with low temperatures. At any time of year, I do not think there would be much precipitation of waxing east of Suez, but there seems every evidence that with vessels carrying Kuwait crude for fairly long voyages under winter conditions, unless heating of cargo is adopted, wax deposition is going to occur. I believe my friends in B.P. will confirm that it is paraffin wax that is the cause of the trouble.

A. F. Dabell: Has any provision been made for a crisis?

J. M. Dougary: When you say "Crisis," I am not quite sure what you mean. An international crisis, or an operational crisis in Kuwait? If it is an international crisis, there is not much we can do about it. If it is an operational crisis in Kuwait, we have a certain amount of cover, and the facilities which have been provided were designed to take care of this sort of thing. When I went through the schematic arrangement, I mentioned the two parallel gravity line systems ending in two switchgate manifolds, the gravity line systems being cross-connected at both the tank farm end and at the shore terminal end. (On the tank group arrangements too, as Fig 2 indicates, the very full flexibility which has been provided also acts as a safeguard in case of an operational crisis.) In the event then, of say a major fire of one section of the loading facilities we should still be able to carry out, although on a limited scale, exports from the other one. There is therefore some duplication of facilities and a certain amount of dispersal to cater for a crisis of an operational kind which in any organization is bound to happen sooner or later—we always hope, later.

H. Hyams: In regard to automatic equipment for measurement, I would like to know whether the author agrees that unless one employs a whole range of automatic instruments in oil measurement operations—and by a whole range I mean not only the instruments required for automatic gauging of oil levels and average oil temperatures in tanks, but also automatic equipment for measuring gravity and for sampling—one does not really achieve much economy in manpower or in labour time. It appears that even if the loading installation convinced both local Customs and the consignees of the high and consistent accuracy of automatic gauging equipment and automatic temperature measuring instruments, such as the Weston thermometer, the loading of cargoes still involves the use of operators to proceed to the top of the tank to draw samples for gravity and for quality determination in the laboratory. A quality certificate is always required, and average samples are also wanted for the determination of B.S. & W. in suspension in the oil so as to arrive at the net quantity of crude being shipped. While samples are being drawn for these purposes, gauging and temperature measurement by manual means can be carried out at the same time. Would Mr Dougary therefore agree that partial installation of expensive automatic measuring equipment does not yield a worth while economy where cargo loading is concerned?

J. M. Dougary: No, I do not agree entirely with Mr Hyams' suggestion. I must say it would be a matter of great gratification to me if we had automatic gauges, automatic temperature samplers, and gravity samplers which could be relied on and which would be acceptable

for fiscalization purposes. That is the goal I hope we shall reach in the not too distant future, but even the present operational aids undoubtedly lead to an appreciable saving in manpower. For instance, the remote reading liquid level gauges. As I have said, we normally have eight tanks filling from the field and eight to ten tanks in movement for export purposes. Without the liquid level gauges for operational purposes these eighteen tanks would have to be gauged periodically by men going to the top of the tank. With the gauges this necessity is obviated. It is perfectly true, as Mr Hyams says, that for official purposes, royalty, and for shipping purposes it is still necessary for men to go to the tank top to carry out gauging, temperature measurements, and sampling, but what we have done is to eliminate the necessity for this being done for operational purposes, *i.e.* in determining when switching of tanks is necessary, either in filling from the field or for loading purposes, and this has enabled a cut in manpower to be made even with an appreciable rise in export rates simply by virtue of the fact that the men we have got are doing the things that we have no operational aid to help them to do. Thus, the gauging, sampling, and so on for official measurement purposes, but in all the intermediate stages where approximate levels only are required, the liquid level gauges are satisfactory.

G. L. Kennaby: Mr Dougary has informed us of what happens at the other end of the floating pipelines, as it were, and what great efforts he makes to speed up the despatch of tankers and so on. A very interesting paper could also be given on what happens at the receiving end. He may send off his tankers at regular intervals, but unfortunately they do not all run at the same speed, and as a result, there is sometimes a bunching on arrival at the home port. I feel that if an investigation were made of the time it took to discharge tankers on arrival in the U.K., we should find several interesting points which may not occur at Mina-al-Ahmadi. I was thinking, for instance, of the possibility of the pump man on board being bribed by one of his friends to slow down the pumps so that the tanker will miss the tide, and he can spend an extra night ashore!

In connexion with the deballasting of ships, are there any special facilities ashore for receiving ballast from the tankers when they come alongside, and if there are, has Mr Dougary ever found that the deballasting system has proved a bottleneck in the time a tanker spends alongside?

J. M. Dougary: I would like to assure Mr Kennaby, that we occasionally have circumstances not unlike the one he has described. For instance, a ship which was been at sea for eighteen days coming straight into berth and starting to load at 3000 tons/hr which will enable her to complete and sail at, say, 7–8 p.m. It is really quite remarkable how the ship finds it necessary to reduce its loading rate from 3000 tons/hr to 1800 tons/hr, involving her finishing later and sailing at midnight or thereabout.

In regard to Mr Kennaby's query, the answer is "No." We have no deballasting arrangements ashore. Ships are required to come in with clean ballast, and that is discharged normally while the ship is alongside the berth or sometimes immediately prior to berthing. It would require a major deballasting system to handle the ballast from eight ships simultaneously. The large super tankers now in operation discharge ballast at 1500–2000 tons/hr, and in order to take this quantity from four to five vessels at the same time would require enormous pipelines and very considerable facilities ashore. From the very beginning of our operations we have always insisted that ships should come into port with clean ballast, or if this is not done a ship is liable to be asked to vacate the port precincts until she has got clean ballast.

V. F. H. Sampson: Does the author consider that any berth time might be saved by the more expeditious coupling and uncoupling of cargo hoses?

J. M. Dougary: No, because with deballasting time of approx 5–5¼ hr, loading hoses are invariably connected long before the ship is ready to receive cargo. The exception, of course, being the few ships, such as the Norwegian whalers, and some of those loading bulk petrol, which are fitted with completely segregated deballasting systems, and there is then definitely a delay of ¾–1 hr while the hoses are being connected. Otherwise hoses are connected long before the ship has got rid of her ballast and is ready to receive cargo.

N. W. Grey: From the paper it is seen that in 1954 a total of 2497 ships loaded approx 45 million tons of crude oil.

Since there are eight loading berths on the oil pier, would it be correct to assume that the average capacity of each berth was approx 5·6 million tons p.a. or have the submarine berths been used extensively to relieve the load.

J. M. Dougary: As you correctly say, the crude submarine berths are used only intermittently, and therefore no figure for tonnage exported per annum is worth quoting. To a lesser degree, the same thing applies as far as the berths on the oil pier are concerned, since the quantities exported per berth vary quite appreciably. The reason is that on the inside berth of the smaller of the two pier legs, for example, berthing is restricted to ships of a definite size, probably of 18,000 tons max and generally not attempted during the hours of darkness. Similar considerations apply as far as berthing in darkness is concerned on the southern inside berth on the long leg of the pier, restriction not being on tanker size but because of manœuvrability. In general, the berths from which the largest tonnage is exported are the two northern berths on the outside of the long leg of the pier, and the seaward berth on the short leg where the largest ships are normally brought alongside. It is not possible to give a very satisfactory answer because there is a very wide variation in the utilization and size of vessels using the individual berths.

C. E. Blackman: I should like to refer to hydraulic shock again. Probably the Mina-al-Ahmadi lines are so large, and the flow rate and valve closing time is such that shock is not a problem. But as I understand it, when shock is created, it travels at the speed of sound, and I doubt therefore whether the relief valves in the lines will give much protection under shock conditions.

J. M. Dougary: The only answer I can give Mr Blackman is that we have never experienced the development of high surge pressures during shut off operations at the completion of loading. The simple explanation of this is that at the loading rates we use it is not physically possible to shut off the valves at such a rate that high dynamic pressures associated with the flow of oil would develop. In certain circumstances, which I cannot immediately foresee, shutting off the flow completely in a short space of time, might cause trouble but the relief valves and associated lines are 2 inches dia and would allow a tolerable flow of oil.

C. E. Blackman: I know of a case where an ordinary gate valve was shut without undue hurry in a long line, and the resultant shock split the line about four or five miles back.

J. M. Dougary: I can quite see that something pretty drastic might happen if the gate in a gate valve on the loading system dropped and actually stopped the flow,

but I think this is a most unlikely occurrence. The actual control valve on the jetty at the ship's side is a gear operated plug cock.

E. J. Sturgess: I would like to ask Mr Dougary for his views on hose sizes. He spoke of 8-inch, 10-inch, and the possibility of 12-inch hoses. There have been developments in light-weight hoses recently, where the larger diameter hose is rather easier to handle. I would like to know if he has had experience of them, and what his views are with regard to the use of the larger sized hose.

Regarding the hose handling gear on the wharf, I would like to know whether they lift the hoses up to the tanker, and then let the tanker take the hose load over, so that with the difference of tide level, the hose will automatically rise and fall with the tide, or whether the hose is held by shore equipment.

One other point. Is there any minimum distance you have between tankers berthed alongside the wharf?

J. M. Dougary: First, our experience of light-weight hose has not been very satisfactory, and the only place that we have had them fitted was in the submarine berths, and some of the trouble that I mentioned earlier on as having been experienced, was put down to these light-weight hoses collapsing in normal operational duty.

On hose sizes we find that with loading rates of up to about 1700 tons/hr an 8-inch hose is perfectly satisfactory, for there is no pressure drop over the 60-ft length of loading hose, but when one loads at 2000 tons/hr and higher there is a definite restriction on loading rate and there are pressure drops of 45–50 lb when loading at the highest rates. I cannot quote intermediate figures, but at anything over 2000 tons/hr 8-inch hoses restrict loading rates, and we have found that at the one berth which is fitted with 10-inch smooth bore hoses that this has been effective in raising, all other things being equal, the loading rate by as much as 150 tons/hr. (During my absence from Kuwait, 10-inch loading hoses have been installed at a number of other berths with an appreciable upgrading of loading rates resulting. Tests are being carried out now on pressure drops encountered using these hoses at the highest loading rates.)

In regard to the minimum distance on the loading pier between tankers, the jetty was designed to handle on the outside or seaward side of the main pier, reading from south to north, two ships each of 520 ft length (standard T2), at the next two berths, two 620-ft length vessels, with a space of 100 ft between ships. Thus, two T2s followed by two 25,000-tonners, each with a 100-ft spacing. On the inside of the main pier the design was for two 620-ft ships again with a 100-ft space between the two vessels. One of the reasons why we use the seaward berth on the short leg of the pier (formerly used for dry cargo discharge) for the real giants of the tanker fleet is that these vessels of 700 ft or more in length would overlap on to a second berth if berthed on the main loading pier, with the consequent reduction in loading capacity of the terminal.

All hose handling is carried out using shore winches. Ships are not responsible for handling the hoses at all. Periodic adjustment is made during the course of loading and to take care of tidal changes. There is a max tidal rise at the Springs of almost 12 ft, so that on a falling tide at this time on a fast loading vessel there is a very marked fall in level necessitating hose adjustment.

C. E. Blackman: I would like Mr Dougary's opinion as to the max berth occupancy factor if delays are to be avoided. For example, would he consider additional berths are required at an occupancy factor of 65–70 per cent.

J. M. Dougary: I think that at 50 per cent berth occupancy one is all right. In fact, that is the max figure that I have seen quoted for other major crude oil terminals. My personal view is that at between 50 and 60 per cent one would start to run into trouble and, certainly at 70 per cent berth occupancy, I should start adding additional berths. Therefore, probably 60–65 per cent is about the max berth utilization before one starts running into quite serious ships' lost time.

L. J. Shrubsall: I presume that the people at Kuwait serve in the capacity of agents for these ships when they arrive, and in such a capacity could they not prepare and sign the bills of lading as a means of quickening up the despatch of vessels?

J. M. Dougary: The Kuwait Oil Company at the Mina-al-Ahmadi terminal act as charterer's agents and agents generally for practically all tankers using the Mina-al-Ahmadi terminal. I am not at all sure whether some of the customers would be entirely happy with the suppliers of the oil signing the ships' papers as well.

The meeting then closed with a unanimous vote of thanks to Mr Dougary.

FAULTING AND OIL ACCUMULATION *

By G. D. HOBSON † (Fellow)

SUMMARY

A proper study of the relationship of faulting and oil accumulation requires consideration of the vertical distribution of the different layers in relation to the fault displacement as well as the history of the movement.

ACCORDING to the terminology suggested by Illing,[3] primary migration is the transfer of oil from the source to the reservoir rock, and secondary migration is the movement of the oil within the reservoir rock to form an oil accumulation, which for the present purposes is referred to as the initial oil accumulation. Elsewhere, it has been concluded that compaction is the agent responsible for primary oil migration, and that buoyancy aided by any water currents owing to compaction or artesian circulation leads to the formation of the initial oil accumulation.[2]

It is to be expected that an oil and gas accumulation will try to adjust its form, extent, and position in response to any changes in the forces acting upon it. Thus, the initial accumulation may not on all occasions be the accumulation which is now known. In certain circumstances, the initial accumulation may in some senses be transient, a state of affairs which would be covered in part by the phenomenon of differential entrapment described by Gussow [1] and independently termed displacement by Hobson.[2]

Other factors leading to adjustments of the initial accumulation are further tilting or folding of the formations, faulting, change in depth of burial, and erosion, which may initiate or intensify artesian flow or circulation in the reservoir rocks. The conditions under which water flow will cause oil movements have been indicated by Hobson [2] and discussed exhaustively by Hubbert.[4] However, it seems probable that on numerous occasions movements of the initial oil accumulation may be owing to buoyancy, and involve only internal circulation, but not the continuous onward passage of water, *i.e.* oil moves upwards, and is replaced by water which moves downwards.

Oil accumulations are commonly associated with faults, and the faults may, by bringing impervious beds against the truncated reservoir beds, provide part of the present seal. On the other hand, it is suspected that in many instances faults have permitted trans-formational migration of oil from an initial accumulation to provide what may be described as a subsequent accumulation. At times, the faults may play a double role, combining the two functions. Furthermore, faults may allow the loss of oil by seepage at the surface. The role of faulting in relation to oil accumulation is considered in some detail in this paper.

FORMATION OF INITIAL OIL ACCUMULATIONS

The growth of a fault may be long drawn-out, and hence the extent of the fault at the time of secondary migration is of importance. The fault displacement may be such that an impervious bed is opposite the entire broken up-dip end of the carrier (reservoir) bed at its highest point. On the other hand, the broken end may only be partially covered by displaced impervious bed at that point. Alternatively, fault gouge may be present to form a seal. Whatever the nature of the seal at the fault, the position of the seal relative to the top of the carrier bed is of prime importance. If the seal is not present against what is locally the highest part of the carrier bed no accumulation of oil or gas can be retained as a result of the faulting. Nevertheless, any warping associated with the faulting may provide closure by dip and this closure can hold oil near the fault line.

If the fault seal covers only the upper part of the carrier bed an oil accumulation could be built up against it down to the highest spill-under point (Fig 1).

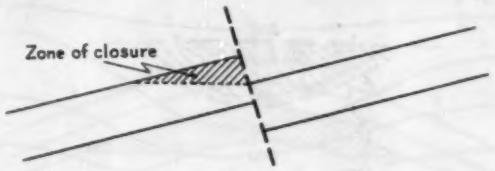


FIG 1

IMPERVIOUS ROCK IS DOWN-FAULTED AGAINST THE UPPER PART OF THE RESERVOIR HORIZON, FORMING A TRAP

Transport of oil and gas could be under the conditions previously indicated as typical of secondary migration. Onward passage of a general water current would be relatively easy because of the incomplete seal.

When the fault seal covers the entire up-dip broken end of the carrier bed the height of the oil accumulation is not limited by any spill-under point associated with the fault. The seal may function as a coarse–fine interface just as in the case of an up-dip wedge-out of a carrier or reservoir bed. The extent to which any water passes on through the seal in the case of secondary migration associated with general water flow is dependent on whether movement through such

* MS received 20 September 1955.

† Royal School of Mines, London, S.W.7.

a seal provides the easiest means of egress. Situations can readily be visualized wherein the volume of water passing through the fault seal may be small, and the main water escape is through the sealing beds overlying the carrier bed. Furthermore, attention in this matter should not be restricted to the fault as seen opposite the oil accumulation. The fault may change

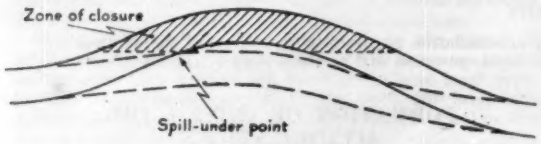


FIG 2

FAULT DISPLACEMENT WHICH IS NOT UNIFORM

In this section, drawn parallel to the fault plane, the full lines show the broken end of the reservoir rock on the upthrown unit; the heavy broken lines show the corresponding end of the reservoir rock on the downthrown unit.

in displacement. If it dies out laterally, then the carrier bed will be continuous where the fault disappears and the main onward passage of water might take place at such points (Figs 2 and 3). On the other hand, change in displacement or in bed thicknesses might put the carrier bed in easy communication, by direct contact or perhaps by minor fractures, with another permeable bed through which the water could escape, but not the oil because of the structurally low situation of the connexion. One of these conditions is shown in the diagram originated by Illing and modified by Hobson, depicting the development of an oil accumulation in a fault trap (Fig 3).

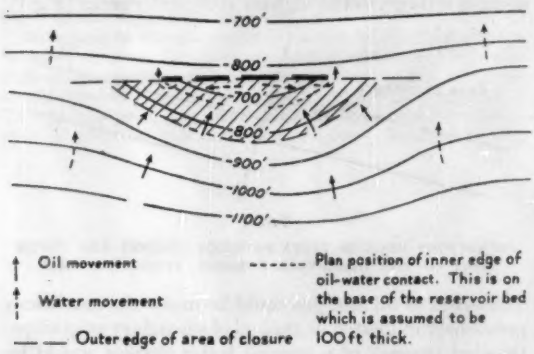


FIG 3

FORMATION OF AN OIL ACCUMULATION ON A FAULTED STRUCTURE WHICH IS COMPARABLE WITH THAT SHOWN IN FIG 2

The heavy broken line shows the sector of the fault where the reservoir rock on the upthrown unit is not in contact with the reservoir rock on the downthrown unit.

When an incompletely compacted source rock is faulted down against a potential reservoir rock, there may be some primary migration of oil and water from the source rock across the fault plane into the reservoir rock. The extent of this migration may be limited, for the zone of source rock from which the fluids will pass laterally in preference to going vertically, because of an opportunity for easier escape, may be quite restricted.

FORMATION OF SUBSEQUENT OIL ACCUMULATIONS

When there is disturbance of equilibrium, such as tilting of the formations, and when the closure associated with an initial oil accumulation is thereby reduced to such a value that the trap can no longer hold all the initial accumulation, the excess oil will move on up dip. Reduction of pressure on the oil and gas accumulation might lead to expansion to a volume greater than the volume of the trap, and the excess would again escape. Water flow might lead to a change in the form of the initial accumulation of such an extent that oil would escape at a spill-under point.

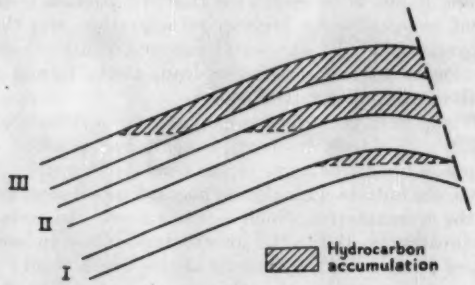


FIG 4

BED I IS ASSUMED TO HAVE AN INITIAL ACCUMULATION, SOME OF WHICH HAS MOVED VIA THE FAULT TO GIVE SUBSEQUENT ACCUMULATIONS IN BEDS II AND III

No more oil can leave Bed I because of the slight arching. Beds II and III have the same oil–water levels.

When the movement of the escaping oil is merely along the bed in which the initial accumulation existed, the function of a fault in relation to the formation of a subsequent accumulation of oil will be exactly the same as for initial accumulations.

However, if the disturbance is caused by a fault which intersects the initial accumulation, then events depend on whether the fault plane becomes an avenue for upward escape, *i.e.* the immediate cap rock has an open fracture, or whether it permits oil transfer from the lower to the higher structural unit until separation of the two parts of the reservoir bed is complete (Fig 6 *b*). In the latter case, oil will move into the higher unit so long as there can be equivalent transfer of water from the higher to the lower unit. The point of water transfer need not be near that of oil transfer, and the whole run of the fault and beyond needs to be considered. It is possible in some cases for oil transfer to cease, because water is no longer able to get from the higher to the lower unit. This will occur when oil in the upper unit extends down to the level of the spill-over point for water in that unit.

When the fault fracture permits oil and gas to escape to the surface a seepage will occur, and the

accumulation will gradually be dissipated. However, there are probably many instances where the fracture merely gives access to higher permeable beds which can act as reservoir beds. Interchange of oil and water between the lower and higher reservoirs is then possible, the oil going upwards and the water downwards. When there is local structural closure against the fault in the lower bed, *i.e.* the bed with the initial accumulation, that closure clearly fixes a limit to the amount of

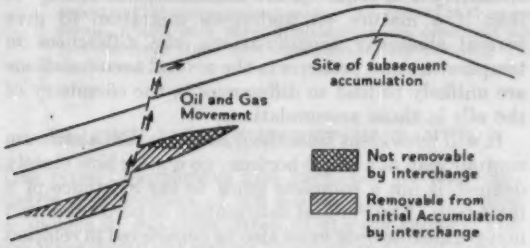

Site of subsequent accumulation
Oil and Gas Movement
Not removable by interchange
Removable from Initial Accumulation by interchange

FIG 5

PARTIAL REDISTRIBUTION OF AN INITIAL ACCUMULATION VIA A FAULT

oil which can escape upwards from the lower bed (Fig 4, Bed I). Furthermore, interchange must clearly cease when water is no longer able to get out of the upper bed and move via the fault to the lower bed. If the interchange succeeds in giving an oil–water level in the upper bed which is the same as that in the lower bed, the process will cease, because equilibrium will have been established via the fault (Fig 4, Beds II and III).

Conditions could exist under which oil escaping from the lower bed up the fault enters the upper bed, and because of the latter's attitude migrates to some trap or surface seep remote from the fault (Fig 5). On other occasions, the form of the beds may be such that a trap exists in an upper bed immediately adjacent to the fault (Fig 4). In this case, the chances of limited interchange are perhaps somewhat greater because the oil in the upper bed might fill down sufficiently far to cut off the spill-over point for water.

If movement of a fault is slow, and if in a sandstone and shale series a sandstone happens to be thicker than the underlying shale, at a certain stage in normal faulting the sandstone in the downthrown block will bridge the interval between two sandstones in the upthrown block as in Fig 6 *c*. As a consequence, upward movement of oil may take place by entering this sandstone in the downthrown block, and then leaving its upper edge to enter its former continuation on the upthrown block. The migration would be by passage through the fault plane, not by travel along the fault plane.

If during secondary migration an open fault is encountered, then it could play roles in determining an initial accumulation comparable with those assigned to such a fault in relation to subsequent accumulations.

Should the fault plane or the near-fault parts of the reservoir beds become choked with tarry material, then interchange would cease. The same would be true if further movement on the fault closed the avenue which hitherto had permitted interchange. Tarry material has been noted near some faults, and it seems possible that its formation may be facilitated by intermingling of oil and water, especially water which is different from that originally associated with the oil.

It would appear that identicality of oil–water contacts for a series of superimposed reservoir rocks suggests free communication between them (Fig 4, Beds II and III). However, it should be noted that if, after attaining such equilibrium, communication was cut off, and the area was tilted, warped, or the depth of burial was changed, then the separate reservoirs would react to these changes independently, and differences in fluid levels could arise. This would obscure the original relationship.

In endeavouring to explain oil accumulations associated with faults, ideally it is necessary to know not only the present fluid distribution and form of the beds, but also the structural history of the area, which involves the detailed form and the state of the faulting at various times in relation to oil migration.

The detailed reference throughout has been to oil and water, although the presence of considerable

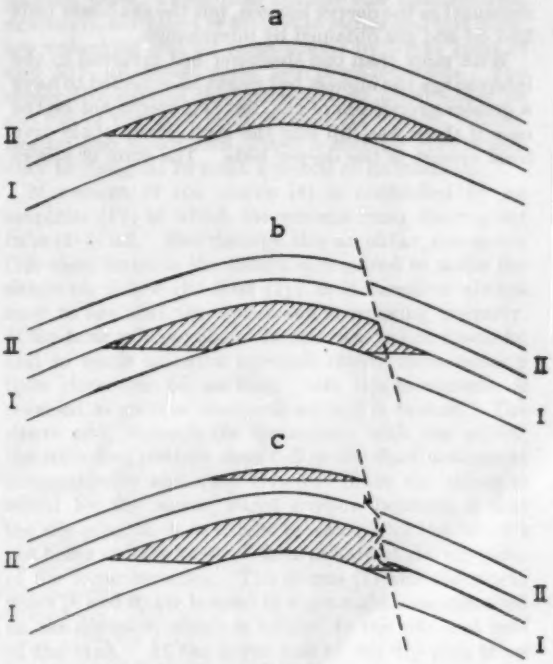


FIG 6

b AND *c* SHOW THE EFFECTS OF PROGRESSIVE INCREASE IN FAULT DISPLACEMENT ON THE INITIAL ACCUMULATION IN BED I (SHOWN IN *a*)

The permeable Bed II is thicker than the shale separating Beds I and II, and in *c*, in the downthrown unit, it permits communication between Beds I and II in the upthrown unit.

amounts of gas is implicit in some of the statements relating to volume changes of the accumulation on change in depth of burial. Rise up a fault implies a change in depth of burial, and in a closed system, with mere interchange of water and hydrocarbons, the pressures must be such that there is volumetric equivalence in the interchange. It will also be apparent that much that has been written about oil and water would apply also to water and gas, or to oil and gas.

When there is free gas in addition to dissolved gas in the initial accumulation, if there is no structural closure adjacent to the fault in the lower bed, all the free gas will take part in the interchange with water in higher permeable beds. However, if there is structural closure adjacent to the fault, and this is greater than the height of the gas cap, only oil with gas in solution will be involved in the interchange via the fault. (Owing to the lower pressure at the higher level some gas would be set free to give a gas cap and, correspondingly, some gas would be driven into solution in the lower accumulation if the system as a whole cannot expand during the interchange.) Free gas and some oil would then remain in the lower horizon, even if interchange went to a limit determined by the closure in the deeper bed. Should the closure be less than the height of the gas cap, then interchange might go to such an extent that only gas remained in the deeper horizon, but the shallower beds had oil and gas obtained by interchange.

With more than one shallower bed involved in the interchange the highest bed might be expected to have a greater proportion of gas, but this might not be the case if there was dip into the fault which could give local closure in the deeper beds. The state of affairs is dependent on the detailed form of the beds near the fault.

If a series of superimposed oil accumulations lie on a faulted structure, and those accumulations have been wholly derived from a single deeper homogeneous initial accumulation, they should be chemically identical, unless in the course of migration there has been extensive reaction with salt-water or other materials. The effects of temperature and pressure on the chemistry of a crude oil are debatable, but it may be that if a mature oil undergoes migration to give several shallower accumulations, the differences in temperature and pressure in the several accumulations are unlikely to lead to differences in the chemistry of the oils in those accumulations.

It will be evident from the discussion that a stratum contour map of a single horizon, no matter how closely defined, is not a complete guide to the existence of a fault trap. The vertical distribution of permeable and non-permeable beds must also be considered in relation to the fault displacement, as well as any indications of the history of fault movement, although there may be cases where fault gouge or other material may afford a seal when the distribution of the different types of beds appears unfavourable.

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NEW METHODS FOR THE MEASUREMENT OF OIL QUANTITIES

By O. FALK *

SUMMARY

After study and investigation extending over many years, instruments first devised for use in the measurement of gases have been successfully adapted to the measurement of the levels of liquid surfaces and therefore to several aspects of oil measurement work. According to their particular applications, these new instruments take various forms, which with their applications are described substantially in the order in which they were developed. Results from these new instruments and methods compare favourably with those from conventional routine methods.

VOLUME MEASUREMENT IN TANKS

THE types of apparatus first developed for the volumetric measurement of oils rely on very precise dips or gauges in dip-pipes fitted in storage tanks. The dip-pipes damp out ripples or waves on the oil surface and give a still oil surface for level measurements. The volumes of oil stocked in the tanks and, by difference in stocks, volumes of oil received or delivered

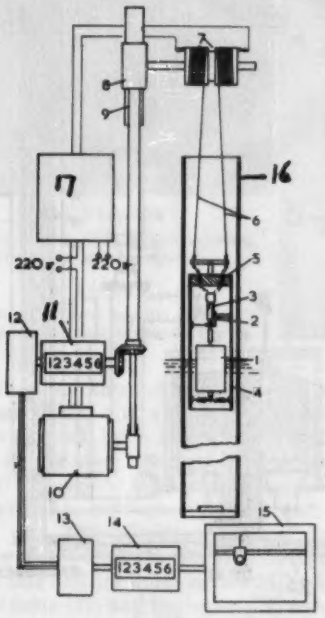

FIG 1

TANK-GAUGE FOR LIQUID HEIGHT AND VOLUME MEASUREMENT

may then be calculated from the tank tables in the usual way, but with exceptionally high precision. For reduction to standard temperatures of the oil it is then necessary to measure also the temperature volumes so measured, or for calculation of oil weights, and the specific gravity of the oil.

As shown in Fig 1, in these tank-gauge devices a float (1) moving without friction carries above it a light plate (2), which on very slight vertical movement in turn operates a vacuum mercury-contact tube (3) held in a sleeve (4) within the dip-pipe (16). The contact tube is connected with two 0·3-mm stainless-steel suspension wires (6), which pass through an insulating piece (5), and its operation makes or breaks a circuit through these wires. The current needed is only 0·03 mA at about 3 V, and this is well below the maximum current strength officially permitted for use in potentially explosive atmospheres. The suspension wires, which pass around two stainless-steel drums (7), machined or ground to radius and insulated, are wound on and off these drums by worm gears (8 and 9); all these parts are precision-made. The motor (10) driving the gears may be fitted either on the top of the tank or at its foot, as desired. Rotation of the motor also drives a counter (11), which may be designed to print a record of its readings.

Movement of the sleeve (4) is controlled by an amplifier (17) to which the current from the contact tube (3) is led. Fed through this amplifier, the motor (10) then turns in the direction required to make the sleeve (4) follow the float (1); it is therefore always easy to see that the apparatus is working properly. If the tank is being filled, the sleeve is pulled upwards, and so tends to move upwards rather more quickly than does the oil surface; but this movement is reversed as soon as electrical contact is broken. The sleeve and, through its connexions with the motor, the recording counter then follow the float movement automatically and very closely. Since the sleeve is raised by the motor, slight friction between it and the dip-pipe, such as might be caused by the latter's not being strictly vertical, does not affect the precision of the measurements. The drums (7) and the worm gears (8 and 9) are housed in a gas-tight case mounted on the dip-pipe, which is welded to the side and roof of the tank. At the lower end of the dip-pipe there is a fixed dip-plate or strike-plate; the float can be made to move into contact with this plate, and so the levels of the oil in the tank may be measured from this datum level. Normally, however, only differences

* Director of the Norwegian Bureau of Measure and Weight.

in level before and after receipts or deliveries of oil need be measured.

REMOTE READINGS

A transmitter (12) may be connected to the counter (11), and a receiver (13) with a recording counter (14) controlled by the transmitter may be installed at any point or points desired, *e.g.* in distant offices; or a counter so controlled may be taken aboard ship, and a watch kept there on the progress of loading or of bunkering.

MEASUREMENT OF LOSSES

To measure loss by evaporation or leakage of the oil, a level-recorder (15) whose pen records graphically the counter readings or their equivalent may be used. A single level-recorder may be switched over from one tank-gauge instrument to another, and so serve for loss measurement on several tanks, while on its paper may be noted the time at which each loss test began. The recorder should be connected after the tank-gauge has been brought into operation, and the recording counter set to zero. The counter will record a change of as little as 0·05 mm in the level of the oil surface. The pen of the recorder may conveniently amplify the changes in oil surface level by 5, a change of 0·2 mm in this level then causing the recorder pen to move 1 mm on the paper.

MEASUREMENT OF OIL BY WEIGHT

Fig 2 shows the principles on which a tank-gauge has successfully been designed for direct measurement of the weights of oil received into or delivered from storage tanks, without measurement of either the temperature or the specific gravity of the oil. A 27-mm brass dip-pipe (1), which opens at its top into a gas-tight chamber (26), carries near its top a side-branch (14) that passes into the vapour space of the storage tank through the tank side (3). The lower end of the dip-pipe is led into the bottom of a container (2), and near the top of this container is the open end of a pipe (25) connected through the tank wall (3) to a level near the bottom of the storage tank.

Although not shown in Fig 2, the container (2) is fitted with gauge glasses over much of its height. The level at which the container is placed is chosen so that if the oil in the storage tank is reduced in quantity to its lowest working level, the plane of the oil surface, extended outside the storage tank, will cut container (2), most conveniently near its mid-level, *e.g.* at L. Dip-pipe (1) and container (2) and its gauge glasses are first filled with water, and connexion (25) to the storage tank is opened. Water is then drawn off through a valve and connexion (not shown) until, as read on the gauge glasses, the interface between the oil so drawn into the container and the water still left in it is substantially at level (L).

A short brass rod (5) carrying a simple contact (6) insulated by a glass tube from contact with the dip-pipe (1) hangs in that pipe by a stainless-steel wire (4). Much as described above in connexion with Fig 1, the suspension wire passes over insulated pulleys (7 and 8) to be wound on to the stainless-steel drum (10), which is machined to radius and which is driven

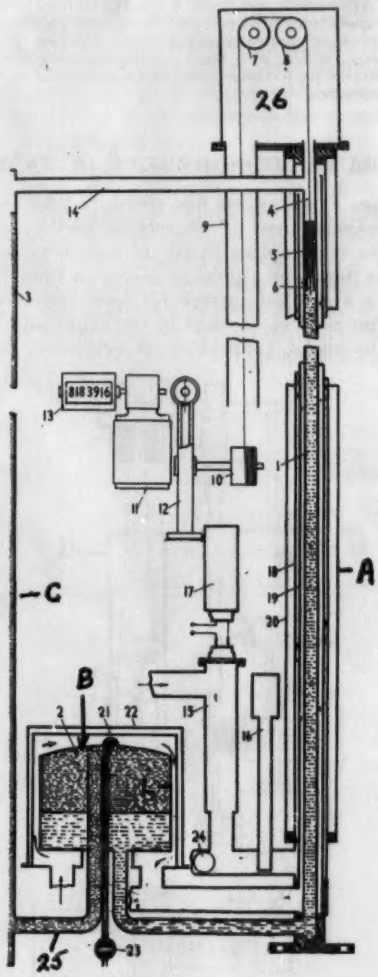

FIG 2

TANK-GAUGE FOR LIQUID WEIGHT MEASUREMENT

through precision-made worm gears by a motor (11) connected to a counter (13). An electric current, of 0·03 mA, is passed through wire (4), contact (6), the water in the dip-pipe, and to earth through the dip-pipe itself. Movement of the contact is controlled by an amplifier, which alters the sense of rotation of the motor so that the contact follows the water surface in its movements.

INCREASE IN PRECISION OF MEASUREMENTS

Reckoned from the level of the oil–water interface in container (2), the head of water in the dip-pipe will always be in hydrostatic balance with the head of oil in the storage tank; the temperature and density of the oil therefore need not be considered in determining the oil weight. The low coefficient of expansion of water, about one-seventh of that of oil, makes it a good medium for frictionless hydraulic weighing. High precision is attained if the temperature of the water is kept constant, preferably at 30° C, which is slightly higher than the highest air temperature in summer.

A satisfactory temperature control arrangement is shown in Fig 2. A brisk current of air, whose path is indicated by arrows, comes from a blower (not shown), and passes through a heater (15) regulated by a thermostat (16) and a relay, the volume of the air being controlled by a throttle-valve (24). The heated air then passes upwards between two pipes (18 and 19) concentric with the dip-pipe (1), and returns downwards between pipe (19) and the dip-pipe itself, pipe (20) affording external insulation. Part of the warmed air is also blown around container (2) between this and its inner cover (21). The space between the inner (21) and the outer (22) covers forms a suitable insulation. Unless the water is heated, it may be necessary in winter to add an anti-freeze compound to the water. The dip-pipe may be fitted inside the tank, but if the temperature in the tank is very variable, this arrangement cannot be recommended; in any case, container (2) must be placed outside.

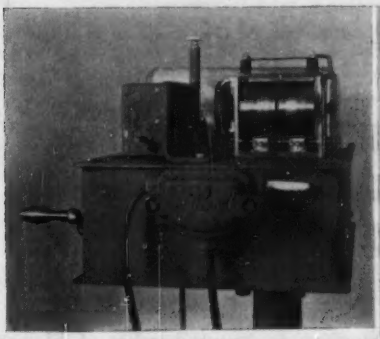

FIG. 3 (*above*)
HEAD OF TANK GAUGE INCORPORATING MOTOR OR HAND DRIVE

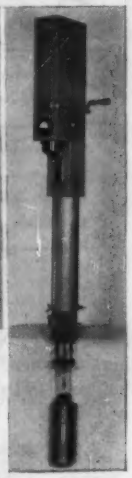

FIG 4 (*right*)
TRANSPORTABLE TANK GAUGE, SUITABLE FOR TANK SHIPS AND STORAGE TANKS

The simplest construction for the tank-gauge is also shown in Fig 2 in the positions 10 to 13 inclusive. The tank-gauge may be driven by motor as shown in Fig 3, and this is probably the more convenient arrangement; but hand drive is always provided as well as motor drive. Thus, in the event of current failure the handle (*left*) may be rotated. The instrument incorporates three amplifiers, each controlled independently by a separate switch. As a safety precaution, the whole of the electrical circuit is contained in an explosion-proof box.

Fig 4 illustrates a transportable tank-gauge, driven by hand only. This apparatus is especially suitable for tank ships because dip readings can be made in a very short time. The operation of a switch enables the height of the water below the oil also to be measured. The e.m.f. is provided solely by means of a dry electric battery.

TANK CALIBRATION: CHECKING OF TANK CAPACITIES

By use of the apparatus, tank capacities may be checked without the use of strapping tapes and without taking the tank out of use. For this, small weighed batches of oil, *e.g.* 3000–5000 kg, are filled into the tank when it is already filled to depths of 1, 4, 7, 11, and 13 m. The counter of the apparatus is read both before and after each such addition, and the increase in counter reading is calculated. The known weight of each batch is then divided by the corresponding increase in counter reading, when if the tank is truly cylindrical, the quotients obtained should be constant for all batches. In practice, however, small variations are to be expected; the mean quotient K is then calculated from all the batches, when for oil of any specific gravity the weight W of any batch delivered from (or received into) the tank is obtained by multiplying the mean quotient or tank constant K by T, the change in counter reading during the delivery (or receipt) of the batch; $W = KT$. The weighed batches required in this type of calibration may be obtained by weighing a rail wagon or a road wagon on a weighbridge, or from some other carefully calibrated container.

PRACTICAL TRIALS AND RESULTS

Many practical trials have been made successfully, but only a few typical results are quoted here.

A set of 154 oil dips or gauges were taken by the earlier form of tank-gauge in a working tank to which this had been fitted, and for comparison, these dips were also taken in the usual routine manner. The sum of the dips taken by tank-gauge was 31·5 mm less than the sum of those taken in the ordinary way, *i.e.* on average a tank-gauge reading differed by 0·5 mm from a routine reading. It follows that errors in the calculated weights of batches of oil delivered from tanks arise more from errors in measuring the temperature or the specific gravity of the oil than from errors in dip or gauge. As is shown below, these errors are eliminated by the use of the tank-gauge for direct measurement of oil weights.

Table I sets out results obtained in the model tank shown in Fig 5. The tank-gauge apparatus was used to control a mercury contact moving in the 8-mm

TABLE I

Small-scale Trials

Grams		Difference		Temp, ° C	
Weighed	Gauged	Grams	Per cent unheated	Water	Oil
512·0	515·0	+3·0	+0·385	17·5	17·1
501·5	500·1	−1·4	−0·279	17·8	17·1
503·0	501·8	−1·2	−0·239	17·8	17·1
After warming the oil					
514·4	515·0	+0·6	+0·117	18·1	45·1
505·2	500·8	−4·4	−0·872	18·1	43·0
514·0	516·0	+2·0	+0·39	17·8	32·0
512·0	510·0	−2·0	−0·39	17·8	29·8

glass tube serving as dip-pipe. The first three results in the table were obtained with the oil unheated and at nearly constant temperature. The oil was then heated to approx 45° C, and the results given in the second part of the table show that this change in temperature has no effect on the precision of the weight measurements.

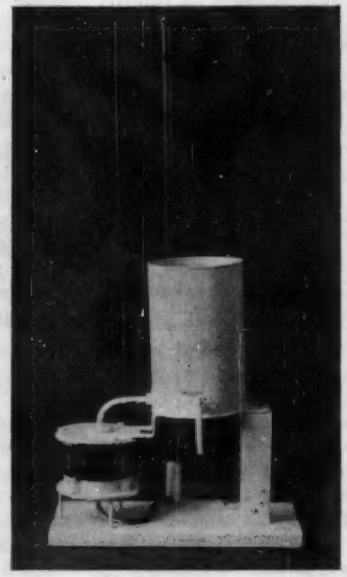

FIG 5

MODEL TANK WITH 8-MM GLASS DIP-PIPE

Again, full-scale trials were made with the weight-measuring tank-gauge fitted to a 600,000-litre tank 29·2 m in diameter. A check, as described above, showed that the tank constant K to be applied to changes in counter readings was $K = 21$, and Table II, which takes the place of the usual tank table, sets out multiples of K. Table II may be read in the usual way; but to minimize the risk of error in reading, the stencil shown in Fig 6 may be and was used in

TABLE II

Simplified Tank Table

Q = 21 × c; 21 = constant; c = counter-figure; Q = quantity in kg

	0	1	2	3	4	5	6	7	8	9
		21	42	63	84	105	126	147	168	189
1	210	231	252	273	294	315	336	357	378	399
2	420	441	462	483	504	525	546	567	588	609
3	630	651	672	693	714	735	756	777	798	819
4	840	862	883	903	924	945	966	987	1008	1029
5	1050	1071	1092	1113	1134	1155	1176	1197	1218	1239
6	1260	1281	1302	1323	1344	1365	1386	1407	1428	1449
7	1470	1491	1512	1533	1554	1575	1596	1617	1638	1659
8	1680	1701	1722	1743	1764	1785	1806	1827	1848	1869
9	1890	1911	1932	1953	1974	1995	2016	2037	2058	2079

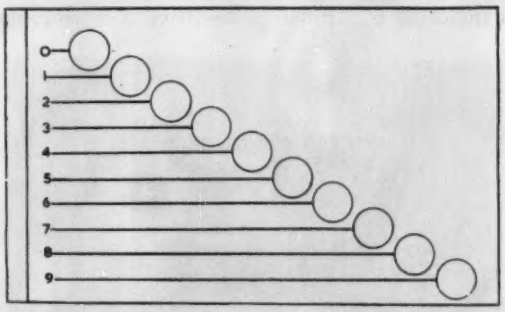

FIG 6

READING STENCIL TO BE PLACED OVER TABLE II

reading it. Nineteen successive batches of oil were then weighed on scales after being withdrawn from the tank. Table III gives these weights in column

TABLE III

Comparison of Batch Weights

Weights of the same batch: (*A*) On scales, (*B*) By tank gauge method, (*C*) By routine method.

No.	*A*, kg	*B*, kg	*C*, kg
1	2,575	2,542	2,655
2	2,575	2,636	2,600
3	2,138	2,195	2,040
4	2,167	2,185	2,138
5	2,602	2,645	2,544
6	2,602	2,562	2,582
7	2,160	2,100	2,196
8	2,593	2,563	2,550
9	3,462	3,296	3,415
10	878	966	830
11	2,595	2,562	2,598
12	3,455	3,432	3,499
13	2,578	2,562	2,539
14	3,455	3,485	3,405
15	4,315	4,410	4,358
16	4,340	4,346	4,298
17	2,177	2,162	2,120
18	2,577	2,542	2,484
19	2,577	2,604	2,658
Totals . .	51,841	51,795	51,414
Differences:			
Kg . .	0	46	427
Per cent .	—	0·09	0·82

A; the weights found from tank-gauge readings are given in column B, while column C gives the weights found in the usual way from gauge-glass readings and oil gravities. From the totals, the usual process is seen to have underestimated the weights of oil delivered by about 0·8 per cent on average, while the tank-gauge weights were correct to 0·09 per cent. The much higher precision obtainable by the use of the tank-gauge is clearly shown, but some further increase in accuracy may still be expected, since in these trials the dip-pipe, although lagged, was not kept at strictly constant temperature by warmed air.

The practical effect of the greater accuracy of the weight-measuring tank-gauge is shown in Table IV, which sets out the main features of a record taken over thirteen consecutive days from a working tank fitted

TABLE IV

Comparison of Batch Weights

Weights of batches: (*A*) By tank-gauge method, (*B*) By routine method: with (*C*) Differences (*A*–*B*).

Batch no.	*A*, kg	*B*, kg	*C*, kg	
			+	−
1	213,000	217,408	—	4,408
2	562,700	561,175	1,525	—
3	85,500	88,592	—	3,092
4	475	0	475	—
5	563,500	562,740	760	—
6	1,165	624	541	—
7	75,470	74,865	605	—
8	475	624	—	174
9	370,300	370,781	—	484
10	178,500	179,262	—	762
11	301,200	300,638	562	—
12	285,500	286,322	—	822
13	104,000	103,109	891	—
14	—	0	—	—
15	224,000	229,680	—	5,680
16	47,500	45,438	2,062	—
17	95,600	94,830	770	—
18	—	—	—	—
19	28,800	30,420	—	1,620
20	—	0	—	—
21	4,020	4,367	—	347
22	6,330,000	6,327,491	2,059	—
23	94,000	101,250	—	7,250
24	—	0	—	—
25	349,300	350,482	—	1,182
26	—	0	—	—
Totals .	9,915,005	9,930,548	10,350	25,821

with this gauge. As it was impracticable to measure the tank constant K for this tank in the way described above, K was determined by taking the total of 9,930,548 kg of oil delivered from the tank during the 13 days in question, and dividing this by 230079, the total of the differences read on the recording counter over the same time. K is then 9930548/230079, or 43·2. Table IV sets out the weights in kilograms of batches of oil measured and delivered, the figures in column A being those calculated from tank gauge readings, and those in column B as calculated by routine procedure. Column C gives with the appropriate sign the differences (A–B).

MEASUREMENTS OF WATER FLOW AND OF OIL FLOW

The principle of the tank-gauge has been applied to measure the flow of water, and no trouble has been experienced with instruments which have been run-

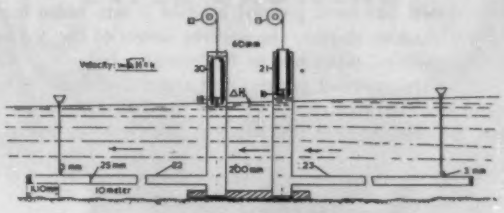

FIG 7

FLOW-GAUGE INSTALLATION

ning for this purpose continuously for over five years. The principle could also be used to measure the flow of oil. As shown in Fig 7, the flow gauge incorporates

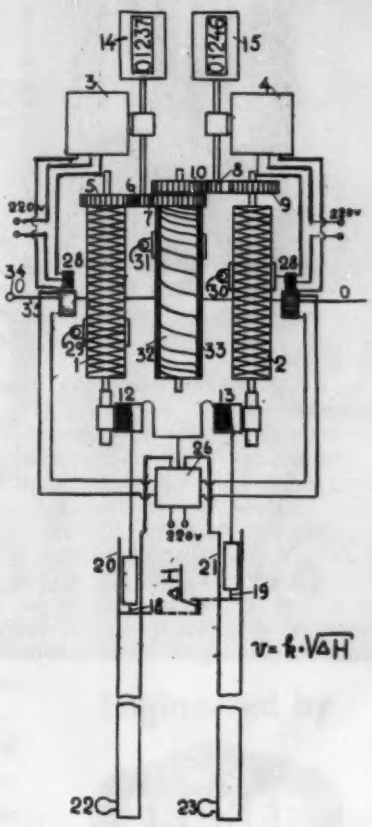

FIG 8

FLOW-GAUGE PRINCIPLES

two tank-gauge floats and simple contacts controlled by amplifiers, each substantially as described above for oil weight measurement. These contacts are sus-

pended in vertical pipes (20 and 21) placed in the river or channel about midway between the triangular marks in the figure. The marked points are chosen at a distance apart that depends on the speed of the current, but the greatest distance needed in practice does not exceed 20 m. Through side-branches otherwise closed but each pierced by two 3-mm holes in a vertical line as shown, the surface levels of the water in the vertical pipes are in hydrostatic balance with those of the marked points, and the difference $\triangle H$ in water-surface level between the marked points may then be measured in the pipes. Between the marks,

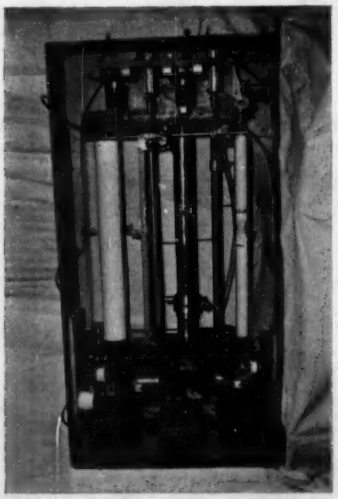

FIG 9
FLOW-GAUGE HEAD

the velocity v of the water current is then proportional to the square-root of $\triangle H$; or $v = k(\sqrt{\triangle H})$.

As illustrated in Fig 8, and as already described, each of the contacts (18 and 19) is kept at the level of the water surface by transmission of a small current through an amplifier to a motor. Following this through for contact (18), a motor (3) turns the counter (14) and through gears (5 and 6) it also turns cylinder (1) and the insulated drum (12). Cylinder (1) is threaded, so that its rotation moves the pen (29) of a pen recorder, recording the level of the contact (18), much as illustrated in Fig 3. Even without alteration of the difference $\triangle H$ in level between the water surfaces in the top pipes, *i.e.* without alteration in the speed v of the current, there is a wide possible range in the average levels of the water surfaces in pipes (20 and 21). For this reason cylinder (1) is provided with both right-hand and left-hand threads, so that its pen may move several times up and down over the paper on which the record is made. Contact (19), drum (13), cylinder (2), motor (4), and counter (15) are similarly connected. The recording pen (30) is set so that when $\triangle H$ is zero, its graph shows no difference in reading from that for pen (29); the water is then still, v becoming zero with $\triangle H$.

AUTOMATIC CALCULATION OF QUANTITY FLOWING

Given the velocity v of the current and the cross-section of the channel in which it flows, the volume of water passing in any given time may be calculated in the ordinary way; but provision is made for automatic calculation. Between the two cylinders (1 and 2) is mounted a third cylinder (32), which rotates inside a hollow fourth cylinder (33). Cylinder (32) is driven from cylinder (2) through the gears (8, 9, and 10), and cylinder (33) is driven from cylinder (1) through gears (5, 6, and 7). A pin attached to the recorder pen (31) passes through a slot in the hollow cylinder (33), and by its engagement in a parabolic thread cut in cylinder (32) causes pen (31) to trace out the velocity curve $v = k\sqrt{(\triangle H)}$, from which by automatic integration the flow may be continuously recorded. When the flow of oil in pipes is measured, it is necessary to use a combination of communicating tubes as shown in Fig 2.

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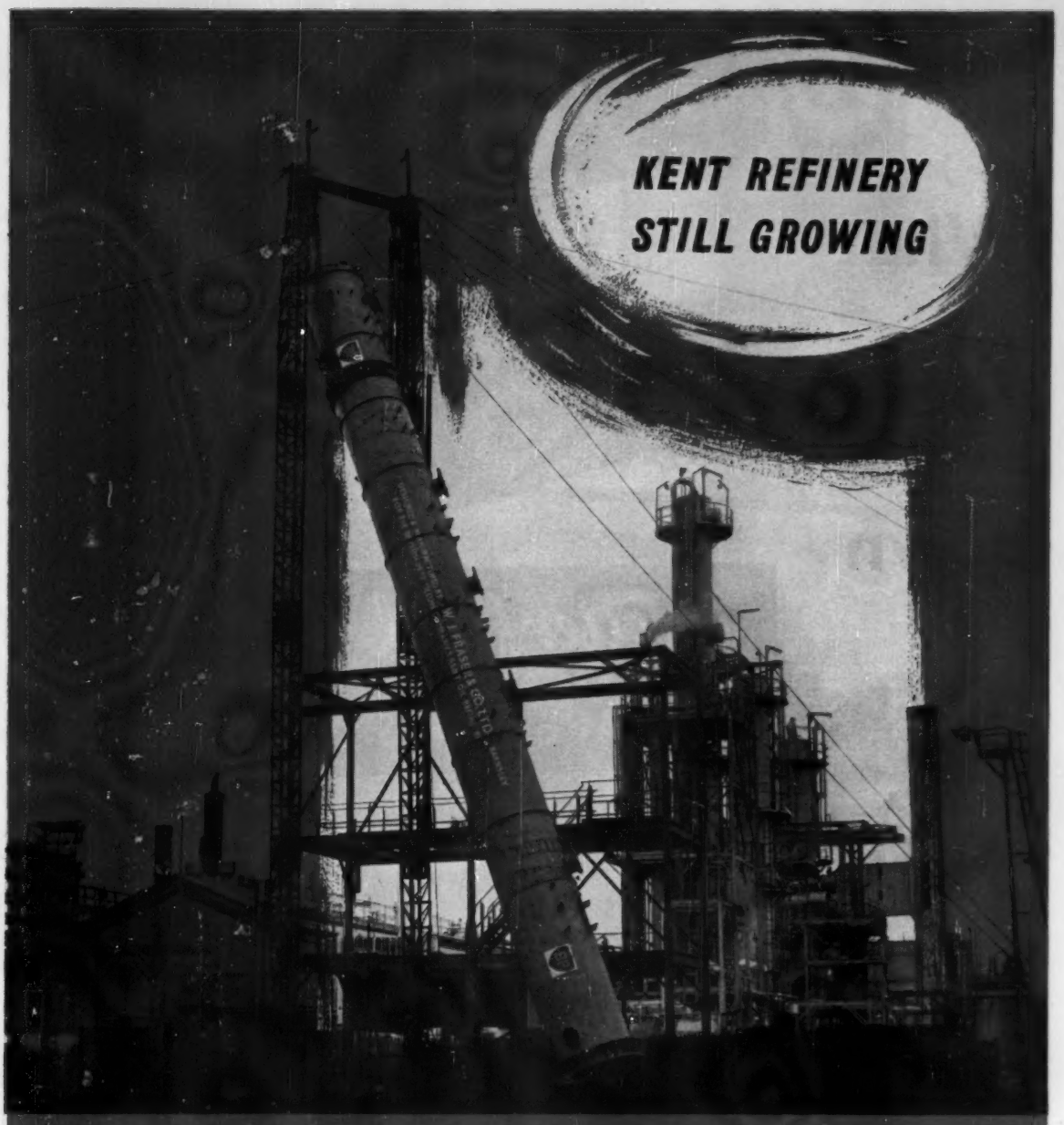

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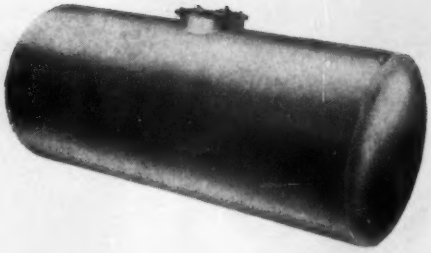

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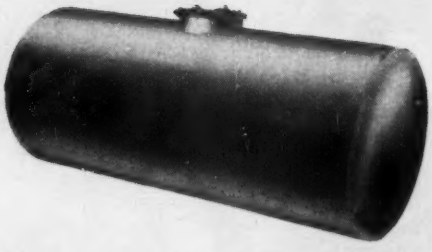

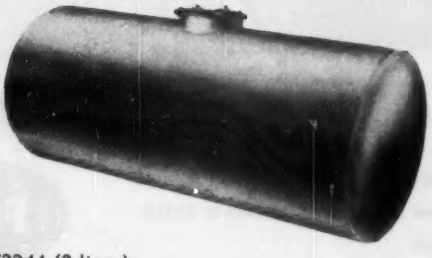

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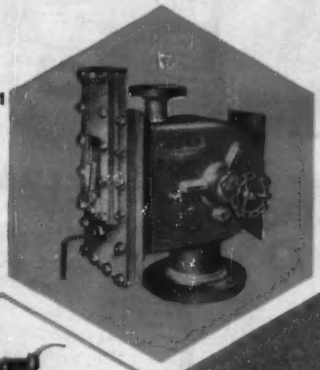

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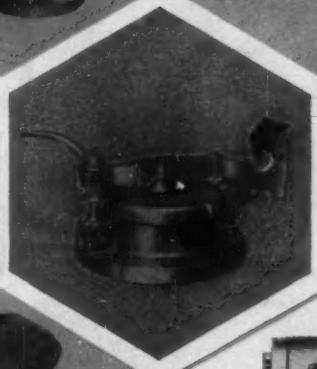

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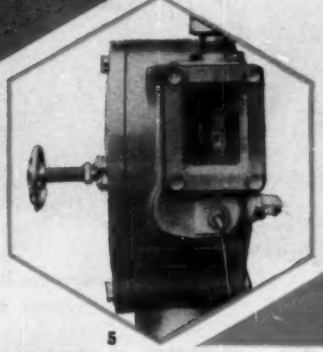

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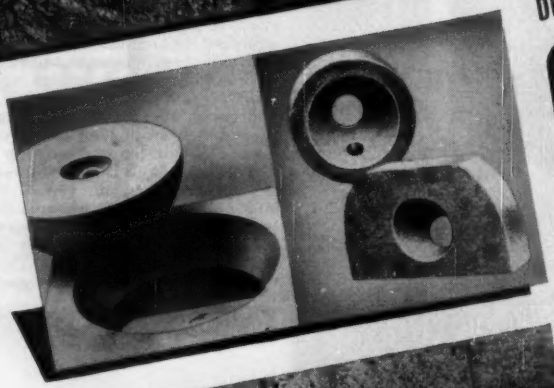

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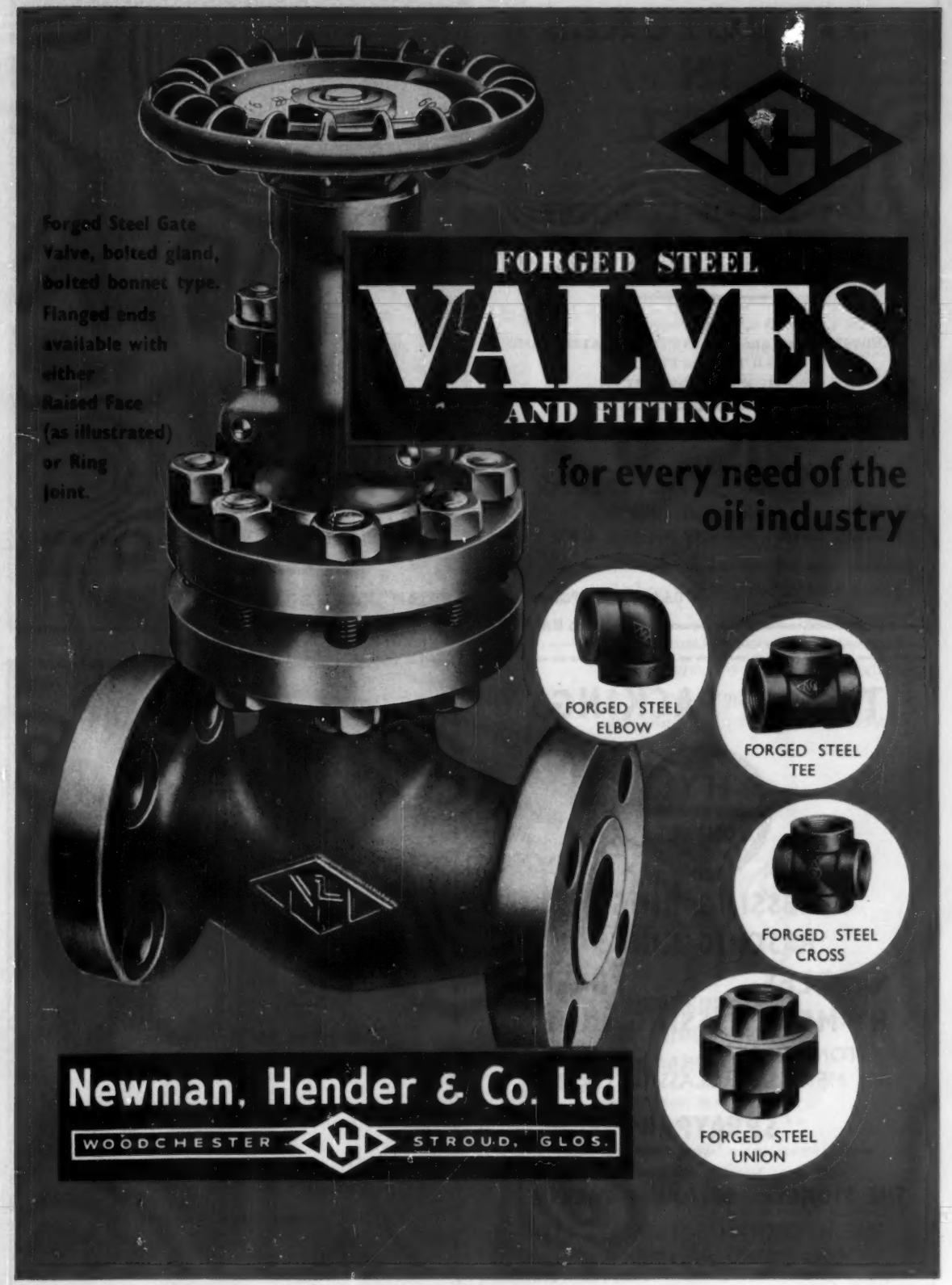
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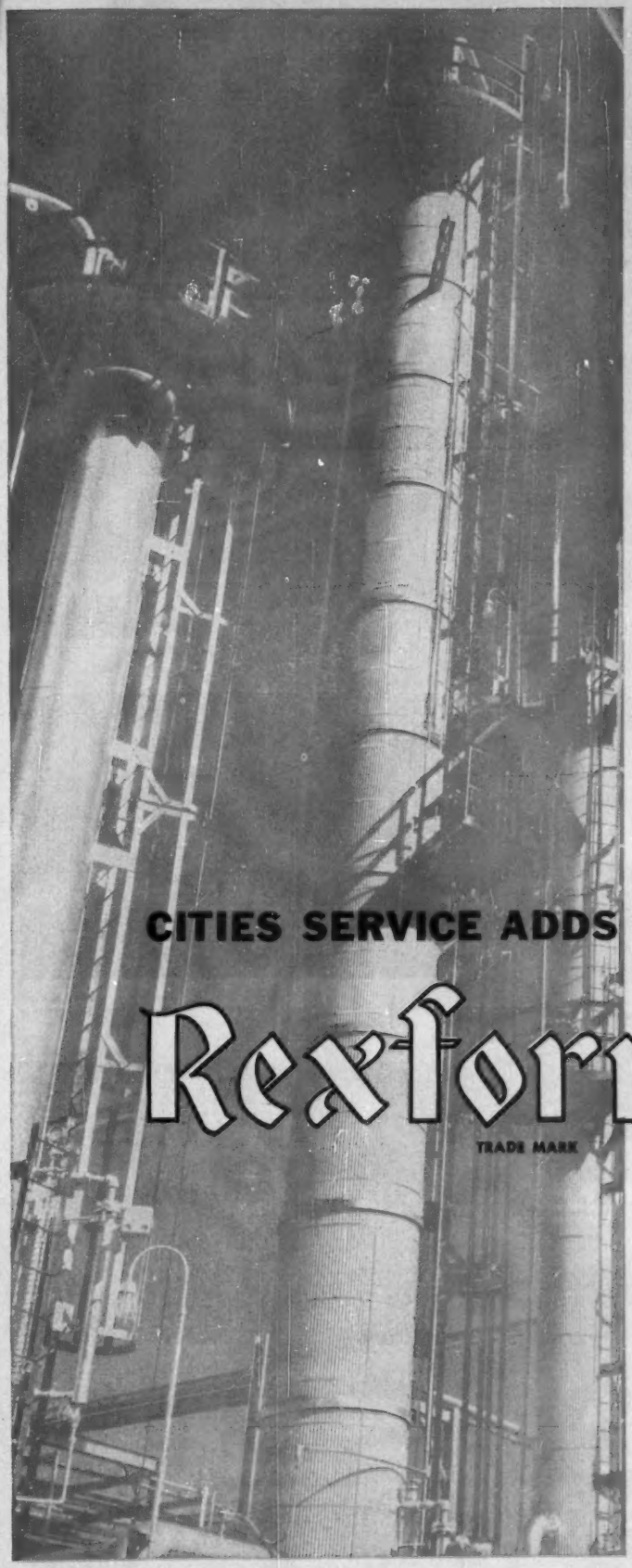

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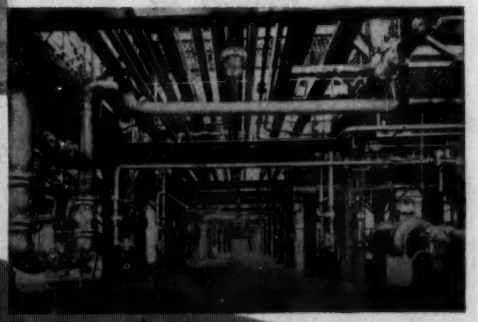

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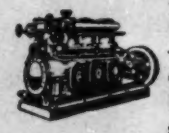

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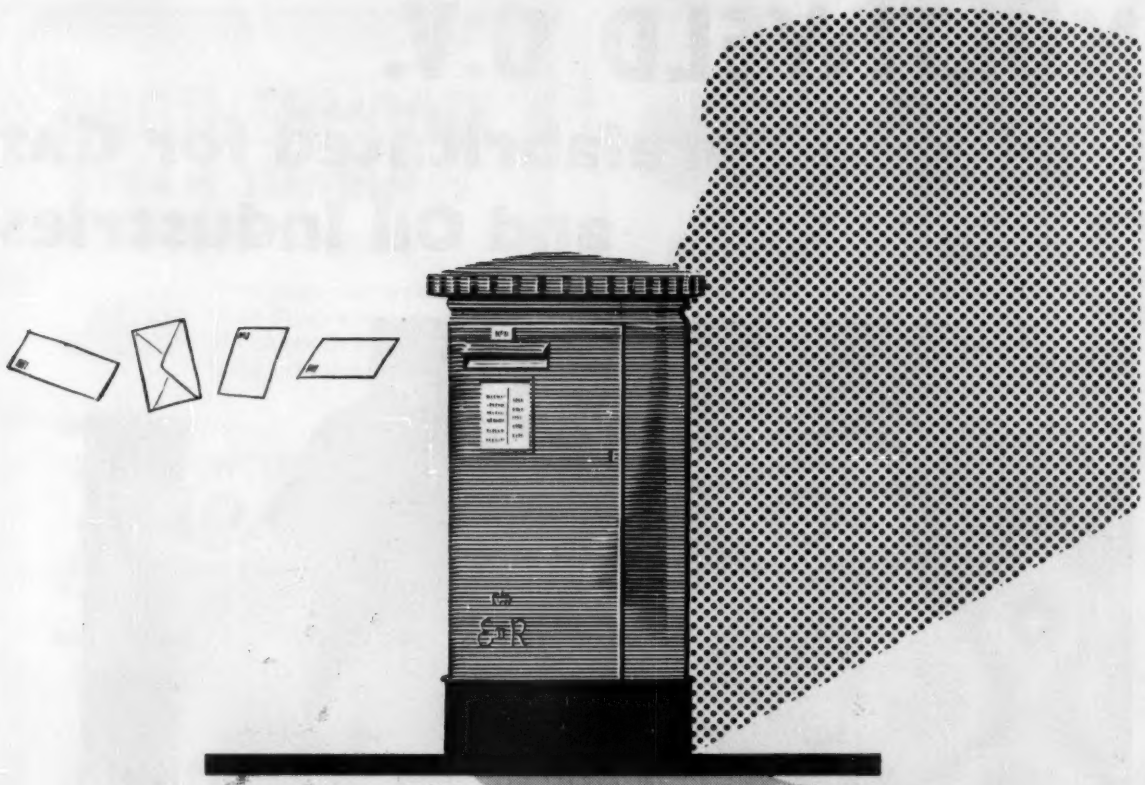

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